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BILTHOVEN, THE NETHERLANDS

Addendum to RIVM Report 601014 003 (Integrated Criteria Document Lead)

ECOTOXICITY OF LEAD
Aquatic and terrestrial data

J.A. Janus September 2001

Background report to RIVM reports 601501 001 (Crommentuijn et al., 1997), 601014 003 (Janus et al., 1999), 711701 013 (Lijzen et al., 1999) and 711701 020 (Verbruggen et al., 2001).

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1 PREFACE

This report contains aquatic and terrestrial ecotoxicological data on the heavy metal lead (Pb), providing an overview of laboratory studies with inorganic lead compounds and organic lead compounds (alkyl lead). The data focus on long-term toxicity studies from which chronic ***"No Observed Effect Concentrations" (NOEC values)*** could be derived. The evaluation of these data, covering references up to 1991, was performed in the framework of the "Integrated Criteria Document Lead" [ICDL, first draft: November 1991; final report: September 1999 (Janus et al., 1999)], in order of the Netherlands' Ministry of Housing, Spacial Planning and the Environment *(Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu, VROM).*

Chronic NOEC values for inorganic lead were used for the derivation of ***Environmental Risk Limits (ERL values)*** for inorganic lead in soil, groundwater, surface water and sediment, in the framework of the project "Setting Integrated Environmental Quality Standards" and the project "Risk in Relation to Soil Quality".
The risk limits derived in the framework of the project "Setting Integrated Environmental Quality Standards", aimed at desired levels of protection, are ecotoxicological ***Maximum Permissible Concentrations (MPC values)*** which are based on the "95%-protection level" (indicated as HC5: "Hazardous Concentration for 5% of the species") and ***Negligible Concentrations (NC values)***, which represent the negligible risk level (Crommentuijn et al., 1997). The risk limits that were derived by Crommentuijn et al. (1997) are underlying a number of ***Environmental Quality Standards (EQS values)*** that were implemented in 1997 in the Netherlands' environmental policy.
The risk limits derived in the framework of the project "Risk in Relation to Soil Quality", aimed at soil clean-up in cases of serious soil pollution, are ecotoxicological ***Serious Risk Concentrations (SRC_{eco} values)*** which are based on the "50%-protection level" (indicated as HC50: "Hazardous Concentration for 50% of the species") (Verbruggen et al., 2001).

Originally, it was intended to publish an Appendix to the Integrated Criteria Document Lead (ICDL) that would include the ecotoxicological data and other data (including human toxicity, legislation, and environmental and human exposure levels in the Netherlands). However, since the main data were already published in the ICDL, with the exception of the comprehensive ecotoxicological data base (only the ERL and EQS values derived from these data were included in the ICDL), it was decided to publish only the ecotoxicological data in this Addendum to the ICDL, together with the ERL and EQS values that were derived from these data.

A number of the ecotoxicological studies summarised in this report were evaluated by BKH Consultancy (Delft, The Netherlands).

2 ECOTOXICOLOGICAL DATA

2.1 Introduction

The ecotoxicological data base on lead comprises aquatic toxicity data on freshwater and saltwater organisms (Tables 1 to 5) and on terrestrial organisms (Tables 6 to 9), covering data up to 1991. The aquatic data base includes data on organic lead compounds (alkyl lead); all other data are on inorganic lead. The data focus on long-term toxicity studies from which chronic " No Observed Effect Concentrations" (NOEC values) could be derived; NOEC values for inorganic lead were used for the derivation of "Environmental Risk Limits" (ERL values). In addition, long-term studies resulting in effect concentrations (including EC50 and LC50 values) are given. All date refer to "single species" toxicity tests, with the exception of the data on soil microbe-mediated processes, which refer to "multi species" toxicity tests.
Acute toxicity data (EC50 and LC50 values derived from short-term studies) are not included in this report, with the exception of the data on alkyl lead.

With respect to the data on inorganic lead, all aquatic data refer to studies that used soluble lead salts (lead chloride, lead nitrate, lead sulphate or lead acetate) as test compounds. The terrestrial data include a number of studies that used "insoluble" lead salts (lead oxide, lead carbonate) as test compounds.

All toxicity values in this report are expressed as lead, not as the test compound. The aquatic toxicity values are expressed either as the nominal (added) lead concentration in the water or as the actual (measured) concentration. The actual concentrations include the background concentration (Cb) of lead in the water. Almost all terrestrial toxicity values are expressed as the nominal concentration in the soil or other test substrate (litter, manure, sludge, food) used. Actual concentrations in terrestrial studies were reported only by a few study authors. In some terrestrial studies the background concentration (Cb) in the test soil or substrate was reported in addition to the nominal test concentrations.

In some aquatic studies, both the dissolved-lead concentrations and the total-lead concentrations (i.e. the dissolved plus particulate fraction) were measured. These studies show that the actual dissolved-lead concentrations usually were similar to the actual total-lead concentrations, as expected from the relatively low test concentrations in the chronic toxicity studies and the test systems used in those studies (usually renewal or flow-through systems, except in algal tests).

2.2 Derivation of NOEC values

I. If possible, "real" NOEC values were derived, i.e. the NOEC is one of the concentrations actually used in the test. In order of preference:
1) Statistical analysis: the NOEC is the highest concentration (in a series of test concentrations) showing no statistically significant effect (inhibition) compared to the control. Significance level: $p = 0.05$ (if not reported: the $p = 0.01$ level).
2) If no statistical analysis has been applied: the NOEC is the highest concentration that results in ≤ 5-10% inhibition *(*)* compared to the control.

In both cases there must be a consistent concentration-effect relationship, i.e. the LOEC is the concentration at which and above which statistically significant toxicity is found (1) or, when

no statistical analysis has been applied (2), >5-10% inhibition is found *(*)*. It is noted that the NOEC values derived in this report, using the 5-10% inhibition limit to distinguish between the NOEC and LOEC, may deviate from the NOEC values originally derived and published by the study authors. It is further noted that a number of NOEC values are from secondary references; in those cases the criteria for NOEC derivation are not always known.
(*) For the data that were already included in the first draft of the Integrated Criteria Document Lead, a value of 5% was used, while for the data added since, a value of 10% was used, in conformity with more recent RIVM guidelines (RIVM/CSR, 1996).

II. If the "real" NOEC cannot be derived from the data reported, the following procedure is used to derive the NOEC. In order of preference:
1) The NOEC is set at the EC10 level.
2) The NOEC is derived from the LOEC.
If the EC10 is not reported, the NOEC is derived from the LOEC using the following extrapolation factors (according to RIVM/CSR, 1996)
a) NOEC = LOEC/2, in case inhibition at the LOEC is >10% but ≤20%.
b) NOEC = LOEC/3, in case inhibition at the LOEC is >20% but ≤50%.
c) NOEC = LOEC/10, in case inhibition at the LOEC is >50%.
It is emphasised that the derivation of NOEC values from LOEC values is mainly limited to the microbial toxicity data (microbe-mediated processes) and that, with one exception, <30% inhibition was found at the LOEC values that were used to estimate NOEC values.

2.3 Selection of NOEC values for ERL derivation

The NOEC values that have been used to derive Environmental Risk Limits (ERL values) for inorganic lead in surface water are listed in Table 1 (freshwater organisms) and Table 3 (saltwater organisms). The NOEC values that have been used to derive ERL values for inorganic lead in soil are listed in Table 6 (soil microbe-mediated processes), Table 7 (soil plants) and Table 8 (soil invertebrates). For organic lead (alkyl lead) no ERL values were derived.
It is noted that both the aquatic data base and the terrestrial data base of NOEC values that were used for ERL derivation by Crommentuijn et al. (1997), Lijzen et al., (1999) and Verbruggen et al. (2001), based on the data in the 1997 draft of the "Integrated Criteria Document Lead" (ICDL), included some NOEC values that slightly differ from the values listed in the aforementioned tables in the present report. It is emphasised, however, that the differences (see below for details) do not affect the ERL values, neither the aquatic nor the terrestrial values.

- *Differences in the aquatic data base*:

For the freshwater fish *Pimephales promelas* and the freshwater fish *Salvelinus fontinalis*, NOEC values of 120 and 39 μg/l (dissolved lead), respectively, were used for ERL derivation. These values should have been 170 and 58 μg/l (total lead), respectively, see Table 1, based on the use of NOEC values expressed as total-lead concentrations (either nominal or actual, see further section 3.1).

- *Differences in the terrestial data base*:

Some of the terrestrial NOEC values that were used for ERL derivation included the background concentration Cb (since the NOEC was calculated from the nominal concentration by adding the Cb), while in the current data base the NOEC values are expressed as nominal concentrations, if possible (see further section 3.1). Based on this, one of the NOEC values for respiration was 500 mg/kg d.w (should have been 480 mg/kg d.w, see Table 6) and the geometric mean NOEC for cellulose mineralization was 330 mg/kg d.w. (should have been 260 mg/kg d.w., see Table 6). Furthermore, for the mite *Platynothrus peltifer* a NOEC of 400 mg/kg d.w was used for ERL derivation (due to a typing error); this value should have been 430 mg/kg d.w. (see Table 8).

The chronic NOEC values for inorganic lead that were used for ERL derivation were selected on the basis of several criteria (according to RIVM/CSR, 1996), including:

1. Preferably the design of the study has to be in agreement with internationally accepted guidelines such as the OECD guidelines for the testing of chemicals. However, because the OECD guidelines on ecotoxicological tests only cover a very limited number of different organisms (especially aquatic organisms), also more general guidelines for the evaluation of ecotoxicological studies were used as guidance, especially those mentioned in the RIVM standard operation procedure (RIVM/CSR, 1996).
2. Toxicological endpoints which may affect the species at the population level are taken into account. In general, these endpoints are survival, growth and reproduction.
3. The chronic NOEC has to be derived from a long-term study covering a considerable part of the lifetime of the organism or to cover a sensitive life stage. In this report, a long-term study is defined as a study with a duration of at least four days. It is emphasised, however, that the fact whether or not a NOEC is considered a chronic NOEC is not determined exclusively by the above exposure time limit of four days, but also by the generation time of the test species. For unicellular algae and other microorganisms (bacteria; protozoa), an exposure time of four days or even considerably less already covers one or more generations, thus for these kinds of organisms, chronic NOEC values can be derived from studies with a duration of less than four days. On the other hand, for organisms that have a long generation time, for example fish, an exposure time of just over four days is much too short to derive a chronic NOEC.
4. If for one species several chronic NOEC values based on the same toxicological endpoint are available, these values are averaged by calculating the geometric mean, resulting in the "species mean" NOEC. With respect to this it is noted that the NOEC values should be from equivalent tests, for example from tests with similar exposure times. Species mean NOEC values were calculated for both aquatic and terrestrial species.
5. If for one species several chronic NOEC values based on different toxicological endpoints are available, the lowest value is selected. The lowest value is determined on the basis of the geometric mean if more than one value for the same endpoint are available (see point 4).
6. In some cases, NOEC values for effects on different life stages of one species are available. If from these data it is evident that there is a difference in sensitivity between the different life stages, the result for the most sensitive life stage is selected. The life stage of the organisms is indicated in the tables as the life stage at start of the test (e.g. fish: sac fry) or as the life stage(s) during the test (e.g. fish: eggs → larvae, which is a test including the egg and larval stage).
7. The selected NOEC values include nominal and actual test concentrations. However, from the aquatic data base a number of high nominal NOEC values ($\geq$ 10,000 µg/l) is

rejected, because it is very likely that precipitation of lead will have occurred, thus overestimating the real exposure concentrations. For example, in the study by Sauter et al. (1976) listed in Table 1, precipitation of lead (added as lead nitrate) occurred at 1.000 μg/l in soft (hardness 25-50 mg/l) well water.

8. The selected NOEC values are from tests that used soluble lead salts as test compounds, with the exception of some NOEC values for soil microbe-mediated processes, since in the microbial tests the NOEC values for "insoluble" lead were in the same range as those for soluble lead.

9. Unbounded NOEC values (i.e. no effect was found at the highest concentration tested, indicated by "≥") are not used, with the exception of unbounded NOEC values for soil microbe-mediated processes and soil plants. The data for soil micro-mediated processes and soil plants include a relatively large number of unbounded NOEC values; rejection of these values would strongly limit the NOEC data base.

3 ENVIRONMENTAL RISK LIMITS (ERL VALUES)

3.1 Methods

The ***Environmental Risk Limits (ERL values)*** for inorganic lead in soil and water, derived by Crommentuijn et al. (1997), Lijzen et al. (1999) and Verbruggen et al. (2001), were calculated from the chronic NOEC values by means of statistical extrapolation. RIVM uses statistical extrapolation for the derivation of ERL values from "single species" toxicity data in case there are at least four chronic NOEC values, which have to be for species of different, major taxonomic groups. The aquatic data should preferably include NOEC values for algae, crustaceans and fish; the terrestrial data should preferably include NOEC values for plants, earthworms and crustaceans, to ensure that species differing in morphology and exposure route are included.

There are several statistical extrapolation methods, all assuming that the sensitivities of species in ecosystems can be described by a statistical frequency distribution. Several distribution functions, usually estimated from chronic NOEC values, have been proposed, viz. log-triangular, log-logistic and log-normal. From the estimated distribution a certain percentile value (HC*p*: "Hazardous Concentration for *p* percent of the species") is calculated. Usually the HC5 (i.e. the "95%-protection level") is calculated, assuming that an ecosystem will be sufficiently protected if 95% of the species in that ecosystem will be protected. Crommentuijn et al. (1997) used the method of Aldenberg and Slob (1993), in which a log-logistic distribution of species sensitivity is assumed, for the calculation of HC5 values (95%-protection level). Lijzen et al. (1999) and Verbruggen et al. (2001) used the method of Aldenberg and Jaworska (2000), in which a log-normal distribution of species sensitivity is assumed, for the calculation of HC50 values (50%-protection level). It is noted that both methods results in very similar HC*p* values (e.g. HC5 values) provided that there is a large number of input data, as for lead.
Both methods can calculated confidence levels of the HC*p*. The HC5 and HC50 values derived in the aforementioned reports (and listed in Table A and Table B of this report) are 50% confidence values.

Because lead is a naturally occurring substance, the natural background concentration (Cb) was taken into account in the derivation of the ERL values, using the "added risk approach". In this approach, the NOEC values from the laboratory tests are preferably expressed as the nominal (added) concentration and the HC*p* value that is derived from the NOEC values is considered as Maximum Permissible Addition (MPA), i.e. as the amount of the substance in the environmental compartment that is considered acceptable when added to the background concentration. The Maximum Permissible Concentration (MPC) in the environmental compartment is subsequently calculated by adding the background concentration (Cb) to the MPA (in formula: MPC = MPA + Cb). Thus, the added risk approach assumes that only the amount added to the background level in the test medium and (likewise) the amount added to the environmental compartment due to anthropogenic activities, may result in adverse effects, ignoring a possible contribution of the background concentration. For more data on the "added risk approach" and the underlying assumptions, see Crommentuijn et al. (1997).

The aquatic data include NOEC values for freshwater and saltwater species. Because the NOEC values for freshwater and saltwater species show no statistically significant difference ($p = 0.63$), the two data sets of NOEC values were combined to one data set that was used for

the calculation of the HC5 and HC50 values. It is noted that the HC5 and HC50 values derived from the aquatic NOEC values are for dissolved lead, although the NOEC values used for the derivation of these values are expressed as the total-lead concentration, either nominal or actual *(*)*. The HC5 and HC50 values are considered to be for dissolved lead, because the conditions used in most of the aquatic tests will have favoured the presence of lead in the dissolved fraction (see also section 2.1).
(*) In some aquatic studies, both the dissolved-lead and the total-lead concentration was measured. The NOEC values expressed as total-lead concentration were chosen, to be consistent with the NOEC values from the other studies (in which the NOEC values were usually expressed as nominal concentration and the remaining NOEC values as measured total-lead concentration).

The terrestrial data include NOEC values for soil species (plants and invertebrates) and soil microbe-mediated processes. The NOEC values for soil species are from "single species" tests; those for soil microbe-mediated processes are from "multi species" tests, since microbe-mediated processes (such as C-mineralization) can be performed by different microbial species. Thus, the former tests measure the effect on a specific species, while the latter measure the effect on a microbial population. Furthermore, the former tests measure the effect on single parameters (usually survival, growth and/or reproduction) for a specific species, while the latter measure the effect on a summed parameter (functional parameter, i.e. the performance of a specific process) without knowledge on the specific microbial species that are affected. Based on these differences, the NOEC values for species and those for processes are not combined but used as two separate data sets for the calculation of HC5 and HC50 values.

As mentioned in section 2.3, a species mean NOEC has been calculated (for aquatic and terrestrial species) if there are several NOEC values for the same toxicological endpoint. With respect to the soil microbe-mediated processes there are usually several NOEC values for a specific process. If the different NOEC values for a specific process are from tests conducted in different soils, the values were not averaged, because it is reasoned that the microbial population is soil specific. Only if several NOEC values for a specific process are based on tests in the same soil, the values were averaged.

All terrestrial NOEC values that have been used for the calculation of HC5 and HC50 values were normalised to *standard* soil, defined as a soil containing 25% clay and 10% organic matter (see the explanation in the footnotes of Tables 6 to 9). Thus, the resulting HC5 and HC50 values, as well as the other ERL values derived from these values, are for *standard* soil. The values derived for sediment, using the equilibrium partition method, are also for *standard* soil (i.e. sediment containing 25% clay and 10% organic matter).

3.2 Results

The ERL values for inorganic lead derived by Crommentuijn et al. (1997) in the framework of the project "Setting Integrated Environmental Quality Standards" are listed in Table A. In addition to the Maximum Permissible Additions (MPA = HC5) and ***Maximum Permissible Concentrations*** (MPC = MPA + Cb) for soil, groundwater, surface water and sediment, these authors also derived Negligible Additions (NA = MPA/100) and ***Negligible Concentrations*** (NC = NA + Cb) for these environmental compartments. The factor of 100 between the MPA

and NA is applied to take into account combination toxicity and other uncertainties in risk (hazard) assessment.
The MPC on the one hand and the NC on the other represent the two different ecotoxicological risk levels that are the basis for the ***Environmental Quality Standards (EQS values)*** that are currently applied in the Netherlands' environmental policy with respect to the desired level of protection. The EQS values that are based on the ecotoxicological MPC and NC are the equivalent MPC and "Target value", respectively (see Chapter 4 for further explanation). The current MPC values and Target values for lead are listed in Table C (Chapter 4).
In RIVM Report "Environmental Risk Limits in The Netherlands" (De Bruijn et al., 1999), all MPC and NC values that were derived in the last decade in the framework of the project "Setting Integrated Environmental Quality Standards" have been reported, as well as the underlying (ecotoxicological) data for the approximately 200 substances (metals and organic substances) that were evaluted and the methods that were used to derive the MPC and NC values. The report by De Bruijn et al. (1999) also includes the full report by Crommentuijn et al. (1997) on lead and other metals.

The ERL values for inorganic lead proposed by Verbruggen et al. (2001) in the framework of the project "Risk in Relation to Soil Quality" are listed in Table B. These authors derived Serious Risk Additions (SRA_{eco} = HC50) and ***Serious Risk Concentrations*** ($SRC_{eco} = SRA_{eco}$ + Cb) for inorganic lead in soil, (ground)water and sediment. These risk levels are underlying the "Intervention values" which are applied in the Netherlands' environmental policy in cases of serious pollution (especially refering to soil and groundwater clean-up). The current Intervention values for lead are listed in Table C (Chapter 4). It is noted that Intervention Values are based on both ecotoxicological data (SRC_{eco} values) and on human-toxicological data (SRC_{human} values), the latter taking into account soil ingestion and other human exposure routes such as the consumption of vegetables and (ground)water. The "integrated SRC" for a specific compartment is based on the lowest SRC for that compartment, provided the reliablity of both SRC values (SRC_{eco} and SRC_{human}) is considered equivalent. The report by Verbruggen et al. (2001), which comprises data on lead, other metals and a large number of organic substances, contains the final proposals for the revision of the current Intervention values for the first series of compounds.

Preceding the above report, a pilot report for the methodology to be used for the revision of the Intervention values in the framework of the proces "Risk in Relation to soil Quality", especially those for metals, was published (Lijzen et al., 1999). In this report, in which only data on lead were used to test the methodology, several options were given for both a number of SRC_{eco} values and SRC_{human} values for inorganic lead. With respect to soil, two SRA_{eco} values were calculated, one from the (25% clay and 10% organic matter) normalised NOEC values (as in Verbruggen et al., 2001) and one from the (pH = 6) normalised NOEC values, resulting in SRA_{eco} values of 490 and 450 mg/kg d.w. and SRC_{eco} values of 575 and 535 mg/kg. d.w., respectively. The soil SRA_{eco} and SRC_{eco} based on the clay and organic matter normalised NOEC values, 490 and 575 mg/kg d.w., respectively (the latter rounded off to 580 mg/kg d.w.), were chosen in the final proposal by Verbruggen et al. (2001). For water and sediment, respectively, equal SRA_{eco} values and SRC_{eco} values were given in both reports (no optional calculations in Lijzen et al., 1999).

Table A. ***Environmental Risk Limits (ERL values)*** for inorganic lead in soil, groundwater, surface water and sediment (Crommentuijn et al., 1997): Maximum Permissible Addition (MPA), Negligible Addition (NA), Background Concentration (Cb), Maximum Permissible Concentration (MPC) and Negligible Concentration (NC).
(soil and sediment: for standard soil containing 25% clay and 10% OM)

	MPA[1] (HC5)	NA[2]	Cb[3]	**MPC[4]**	**NC[5]**
SOIL (mg/kg d.w.)	55	0.55	85	140	86
GROUNDWATER (μg/l; dissolved lead)	11	0.11	1.6	13	1.7
SURFACE WATER (μg/l; dissolved lead)					
Freshwater	11	0.11	0.15	11	0.26
Saltwater	11	0.11	0.02	11	0.13
SEDIMENT (mg/kg d.w.)	4,700	47	85	4,800	132

1. MPA soil (55 mg/kg d.w.; 90% CI: 29-90 mg/kg d.w) = HC5 processes; the HC5 species is 64 mg/kg d.w. (90% CI: 20-136 mg/kg d.w.)
   The HC5 values were calculated from the (25% clay and 10% OM) normalised NOEC values.
   MPA water (11 μg/l; dissolved lead; 90% CI: 5-18 μg/l) = HC5: calculated from the combined NOEC values for freshwater and saltwater species (if the NOEC values are not combined, the HC5 is 12 μg/l for freshwater and 6.5 μg/l for saltwater; dissolved lead).
   MPA sediment: calculated with equilibrium partition, from MPA water (11 μg/l; dissolved lead) and $Kp_{sediment - water}$ (427,000 l/kg).
   Note The 90% CI (confidence interval) values are from Verbruggen et al. (2001), not from Crommentuijn et al. (1997).

2. NA = MPA/100.

3. Cb soil and sediment: [Pb] = {50 + L + H} mg/kg d.w.
   L = lutum (clay): 25% in "Dutch standard soil".
   H = humus (organic matter): 10% in "Dutch standard soil".
   Cb freshwater (0.15 μg/l; dissolved lead): calculated from the background concentration for total lead in freshwater (3.1 μg/l, reported by Van den Hoop, 1995), a particulate matter content (S) of 30 mg/l and a $Kp_{particulate\ matter / water}$ of 640,000 l/kg, as follows:
   $Cb\ (dissolved) = Cb\ (total) / [1 + (Kp_{pm-w} * S * 10^{-6})]$
   Cb saltwater and Cb groundwater: from Van den Hoop (1995).

4. MPC = MPA + Cb.

5. NC = NA + Cb.

Table B. ***Environmental Risk Limits (ERL values)*** for inorganic lead in soil, water and sediment (Lijzen et al, 1999; Verbruggen et al., 2001): Serious Risk Addition (SRA_{eco}), Background Concentration (Cb) and Serious Risk Concentration (SRC_{eco}).
(soil and sediment: for standard soil containing 25% clay and 10% OM)

	SRA_{eco}[1] (HC50)	Cb[2]	**SRC_{eco}[3]**
SOIL (mg/kg d.w.)	490	85	580
WATER (μg/l; dissolved lead)	150	<2	150
SEDIMENT (mg/kg d.w.)	63,000	85	63,000

1. SRA_{eco} soil (490 mg/kg d.w.; 90% confidence interval: 270-890 mg/kg d.w.) = HC5O species; the HC50 processes is 520 mg/kg d.w. (90% confidence interval: 360-750 mg/kg d.w.).
   The HC50 values were calculated from the (25% clay and 10% OM) normalised NOEC values. *In addition, Lijzen et al (1999) also derived HC50 values from the (pH = 6) normalised NOEC values, resulting in a HC50 species of 450 mg/kg d.w. and a HC50 processes of 665 mg/kg d.w.*
   SRA_{eco} water (150 μg/l; 90% confidence interval 100-220 μg/l; dissolved lead) = HC50, calculated from the combined NOEC values for freshwater and saltwater species.
   SRA_{eco} sediment: calculated with equilibrium partition, from SRA_{eco} water (150 μg/l; dissolved lead) and $Kp_{sediment, water}$ (427,000 l/kg).

2. Background concentrations (Cb): see Table A. The background concentration in water (surface water and groundwater) is negligible compared to the SRA_{eco} in water.
   The background concentration in sediment is negligible compared to the SRA_{eco} in sediment.

3. $SRC_{eco} = SRA_{eco} + Cb$.
   Based on the human toxicity data, the following SRC_{human} values were derived: 622 mg/kg. d.w. for soil, 3,210 mg/kg d.w. for sediment and 17 μg/l for groundwater (used as drinking water).
   The "integrated SRC values" proposed by Verbruggen et al. (2001) are:
   580 mg/kg d.w. for soil, 3,210 mg/kg d.w. for sediment and 17 μg/l for groundwater (calculated with equilibrium partition, from SRC_{human} for soil).

Note: The $SRC_{eco} = SRA_{eco}$ for water (150 μg/l) is valid for groundwater and surface water.

4 ENVIRONMENTAL QUALITY STANDARDS (EQS VALUES)

The ***Environmental Quality Standards (EQS values)*** for inorganic lead in soil, groundwater, surface water and sediment that are applied in the Netherlands' environmental policy are listed in Table C (VROM, 1999, based on earlier VROM policy papers). For these compartments, EQS values are ***Maximum Permissible Concentrations (MPC values), Target values and Intervention values***, which all three are non-legally binding EQS values. Normally, the MPC and Target value are set at the level of the ecotoxicological MPC and NC (see Chapter 3), respectively. The MPC and Target values indicate the two risk levels for the desired level of protection, the MPC being set as a short-term target and the Target value as the long-term target for environmental policy, the latter to be archieved by 2010 if possible. In the Netherlands' environmental policy. MPC values are applied only for surface water and sediment, not for soil and groundwater (although ecotoxicological MPC values also have been derived for soil and groundwater, see Chapter 3).
Except for the MPC for lead in sediment, the target values and MPC values for lead in soil, groundwater, surface water and sediment are based on the ecotoxicological MPC and NC values derived by Crommentuijn et al. (1997); the EQS values were implemented in 1997. The MPC for lead in sediment was set at the level of the Intervention value (530 mg/kg d.w for *standard* soil and sediment) since the Intervention value is considerably lower than the ecotoxicological MPC for lead in sediment (4,800 mg/kg d.w.; see Table A). The Intervention values for lead in soil/sediment and groundwater, which are primarily based on human-toxicological data, were implemented in 1993.

For lead in air there are ***Limit values*** of 2 $\mu g/m^3$ (98-percentile value of 24-h average concentrations) and 0.5 $\mu g/m^3$ (annual average concentration). Limit values are legally binding EQS values. The limit values for lead are primarily based on human-toxicological data and were implemented in 1987. There are no ecotoxicological ERL or EQS values for lead in air. Crommentuijn et al. (1997) calculated a "Critical air Concentration" (CritCONC(air)) which is the concentration in the air that corresponds to the ecotoxicological MPC in soil. The CritCONC(air) for lead is 0.74 $\mu g/m^3$, calculated from the MPC in *standard* soil (140 mg/kg d.w.) and the Steady-State soil/air Concentration Ratio (SSCRsoil/air: 190,000 m^3/kg d.w.). According to Crommentuijn et al. (1997) it should be stressed that the calculated CRITCONC(air) values (which were calculated for lead and other metals) are to be used as indicative values only, because of the uncertainties in the model calculations (SimpleBox model, adapted for metals).

Table C. ***Environmental Quality Standards (EQS values)*** for inorganic lead in soil, groundwater, surface water, sediment and air in the Netherlands (VROM, 1999, based on earlier VROM policy papers)
(soil and sediment: for standard soil containing 25% clay and 10% OM)

Compartment	EQS	Value	Unit	Framework *(year of implementation)*
SOIL				
	Target value [1] (incl. Cb[5])	85[5]	mg/kg d.w.	SIEQS *(1997)* [6]
	Intervention value	530[5]	mg/kg d.w.	Soil clean-up *(1993)*
GROUNDWATER [2]				
	Target value			SIEQS *(1997)* [6]
	* depth > 10 m (dissolved lead, incl. Cb = 1.6 µg/l)	1.7	µg/l	
	* depth < 10 m (dissolved lead, incl. Cb = 15 µg/l)	15	µg/l	
	Intervention value	75	µg/l	Soil clean-up *(1993)*
SURFACE WATER (freshwater) [3]				
	Target value			SIEQS *(1997)* [6]
	* dissolved lead (incl. Cb = 0.2 µg/l)	0.3	µg/l	
	* total lead (incl. Cb = 3.1 µg/l)	5.3	µg/l	
	MPC			SIEQS *(1997)* [6]
	* dissolved lead (incl. Cb = 0.2 µg/l)	11	µg/l	
	* total lead (incl. Cb = 3.1 µg/l)	220	µg/l	
SEDIMENT (freshwater) [4]				
	Target value [1] (incl. Cb[5])	85[5]	mg/kg d.w.	SIEQS *(1997)* [6]
	MPC [5]	530[5]	mg/kg d.w.	SIEQS *(1997)* [6]
	Intervention value	530[5]	mg/kg d.w.	Soil clean-up *(1993)*
AIR	Limit value * 98-percentile value of 24-h averages	2	µg/m³	Air pollution Act *(1987)*
	Limit value / MPC [7] * annual average	0.5	µg/m³	
	Target value [7]	0.005	µg/m³	

Footnotes Table C

[s] The Cb and EQS values in soil and sediment are for *standard* soil, defined as a soil or sediment containing 25% clay (L: lutum) and 10% organic matter (H: humus).

[1] The "Target value" in soil and sediment depends on the soil type, according to the reference line *[Pb] = {50 + L + H} mg/kg d.w.* for the background concentration (Cb) in unpolluted Dutch soils, thus in *standard* soil and sediment (25% L; 10% H) the "Target value" is 85 mg/kg d.w.

[2] The "Target values" (depth >10 m and depth <10 m) and " Intervention value" in groundwater do not depend on the soil type.

[3] The "Target values" for dissolved lead and total lead in freshwater and the MPC for total lead in freshwater are for *standard* surface water, defined as surface water containing 30 mg particulate matter (40% L; 20% H) per litre.
The MPC for dissolved lead in surface water is for both freshwater and saltwater (see also Table A).

[4] All EQS values in sediment are for *standard* freshwater sediment.

[5] The MPC in sediment is set at the level of the "Intervention value" (530 mg/k.d.w. for *standard* soil and sediment).

[6] SIEQS: project "Setting Integrated Environmental Quality Standards".

[7] The "Limit value" for the annual average concentration in air (0.5 $\mu g/m^3$) is mentioned both as Limit value and as MPC in VROM (1999c). VROM (1999c) also mentions a "Target value" of 0.005 $\mu g/m^3$ for the annual average concentration (based om MPC/100).

5 REFERENCES CHAPTER 1 TO 3

(Note: See Appendix III for the references on the ecotoxicological data summarised in Tables 1 to 9. Appendix III includes references on additional ecotoxicological data on lead.)

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APPENDIX I

ECOTOXICITY – AQUATIC ORGANISMS

(Tables 1 to 5)

Table 1. Chronic toxicity of inorganic lead to freshwater organisms: NOEC values (underlined NOEC values: used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (ug Pb/l)	Reference
Bacteria										
Escherichia coli	-	-	$Pb(NO_3)_2$	-	-	-	-	$NOEC_g$	1,300	Bringmann, 1959a [1,2]
Pseudomonas putida	-	-	$Pb(CH_3COO)_2$	-	-	-	16 h	$NOEC_n$	1,800	Bringmann, 1979 [2]
Microcystis aeruginosa (Cyanophytes)	N	S	$Pb(CH_3COO)_2$	n.m.	7.0	66	8 d	$NOEC_g$	450	Bringmann, 1978 [2,3]
Algae (unicellular)										
Ankistrodesmus sp.	N	S	$PbCl_2$	n.m. (low P; + EDTA)	6.2	27	7 d	$NOEC_g$ (est.)	500	Monahan, 1976 [12]
Ankistrodesmus falcatus	N	S	$PbCl_2$	n.m.	-	-	10 d	$NOEC_g$	500	Devi Prasad, 1982
Chlorococcum spp.	N	S	$PbCl_2$	n.m.	-	-	10 d	$NOEC_g$	1,000	Devi Prasad, 1982
Navicula incerta	N	S	$PbCl_2$	n.m. (no chelator)	8.3-8.4	-	4 d	$NOEC_g$	500	Rachlin, 1983
Scenedesmus obliquus	N	S	$PbCl_2$	n.m.	-	-	10 d	$NOEC_g$	500	Devi Prasad, 1982
Scenedesmus quadricauda	N	S	$Pb(NO_3)_2$	river (sterile)	7.5-7.8	84	4 d	$NOEC_g$	1,300	Bringmann, 1959b
Scenedesmus quadricauda	N	S	$Pb(CH_3COO)_2$	n.m.	7.0	66	8 d	$NOEC_g$	1,900	Bringmann, 1978 [2, 3]
Scenedesmus quadricauda	N	S	$PbCl_2$	n.m.	4.5	-	15 d	$NOEC_g$	3,000	Starodub, 1987
Scenedesmus quadricauda	N	S	$PbCl_2$	n.m.	6.5	-	15 d	$NOEC_g$	500	Starodub, 1987 [12]
Scenedesmus quadricauda	N	S	$PbCl_2$	n.m.	8.5	-	15 d	$NOEC_g$	1,000	Starodub, 1987
Scenedesmus capricornutum						geometric mean		$NOEC_g$	1,300	(n = 5)
Selenastrum capricornutum	N	S	$Pb(CH_3OO)_2$	n.m. (+ EDTA)	-	62	13 d	$NOEC_g$	10	Christensen 1979
Algae (Multicellular)										
Chara vulgaris	A	S	$Pb(NO_3)_2$	n.m.	-	-	14 d	$NOEC_n$	2,100	Heumann, 1987
Cladophora glomerata (1 cm fragments)	N	S	-	n.m. (no EDTA)	8.4	≥35	3 d	$NOEC_g$	300	Whitton, 1967
Protozoans										
Chilomonas paramecium	N	S	$Pb(CH_3COO)_2$	-	-	-	2 d	$NOEC_g$	220	Bringmann, 1981 [2]
Entosiphon sulcatum	N	S	$Pb(CH_3COO)_2$	-	-	-	3 d	$NOEC_g$	20	Bringmann, 1979 [2]
Microregma heterosoma	N	S	$Pb(NO_3)_2$	river (sterile)	7.5-7.8	84	28 h	$NOEC_f$	1,300	Bringmann, 1959b [2]
Uronema parduczi	N	S	$Pb(CH_3COO)_2$	-	-	-	20 h	$NOEC_n$	70	Bringmann, 1981 [2]

(to be continued)

Table 1. *(continued)* **Chronic toxicity of inorganic lead to freshwater organisms: NOEC values (underlined NOEC values: used for deriving risk limits in water)**

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (µg Pb/l)	Reference
Molluscs										
Lymnea palustris (eggs)	A(T)	F	$Pb(NO_3)_2$	tap	7.2-8.4	139	30 d	$NOEC_h$	31	Borgmann, 1978
Lymnea palustris (adults)	A(T)	F	$Pb(NO_3)_2$	tap	7.2-8.4	139	120 d	$NOEC_s$	12	Borgmann, 1978
Crustaceans										
Ceriodapnia dubia (P <1 d → F; levenscyclus)	A(D) A(T) A(D) A(T)	F	$Pb(NO_3)_2$	river ([illegible] µm filtered)	8.2	100	7 d	$NOEC_r$ $NOEC_r$ $NOEC_s$ $NOEC_s$	19 26 ≥ 19 ≥ 26	Spehar, 1986 [4,5]
Daphnia magna (P 2-3 d → F; (life cycle)	-	R	$Pb(CH_3COO)_2$	art. (filtered)	7.2	250	19 d	$NOEC_{r,s}$	1	Berglind, 1985
Daphnia magna (P < 1 d)	-	R	$Pb(CH_3COO)_2$	art. (filtered)	7.2	250	8 d	$NOEC_g$	64	Berglind, 1985
Daphnia magna (life cycle)	-	S	$PbCl_2$	lake	7.4-8.2	44-53	21 d	$NOEC_r$ (est.)	15	Biesinger, 1972 [7]
Daphia magna (P <1 d → F; life cycle)	A	R	$Pb(NO_3)_2$	lake (25 µm filtered)	8.1	225	21 d	$NOEC_r$ $NOEC_s$ $NOEC_j$	250 750 2,700	Enserink, 1991
Daphnia magna (population)	A	F	$PbNO_3)_2$	lake (25 µm filtered)	8.1	225	17 d	$NOEC_{r,s}$	670	Enserink, 1991 [9]
Daphnia magna						geometric mean		$NOEC_r$	40	(n = 4)
Fish										
Brachydanio rerio	N	R	$Pb(CH_3COO)_2$	art.	7.5	100	16 d	$NOEC_s$ $NOEC_h$	120 240	Dave, 1991
Catostomus commersoni (eggs → larvae)	A(T)	F	$Pb(NO_3)_2$	well	6.7-7.1	32-48	60 d	$NOEC_{s,g,t}$ $NOEC_h$	120 ≥ 480	Sauter, 1976 [1]
Esox lucius eggs → larvae)	A(T)	F	$Pb(NO_3)_2$	well	6.7-7.3	31-45	60 d	$NOEC_{s,t}$ $NOEC_{g,h}$	250 ≥ 480	Sauter, 1976 [1]
Ictalurus punctuatus (eggs → larvae)	A(T)	F	$Pb(NO_3)_2$	well	6.8-7.3	25-37	60 d	$NOEC_{s,g}$ $NOEC_{h,t}$	75 ≥ 460	Sauter, 1976 [1]
Lepomis macrochirus (eggs → larvae)	A(T)	F	$Pb(NO_3)_2$	well	6.7-7.2	31-52	60 d	$NOEC_{s,g}$ $NOEC_t$ $NOEC_h$	70 120 ≥ 450	Sauter, 1976 [1]
Pimephales promelas (juveniles)	A(D) A(T) A(D) A(T)	F	$Pb(NO_3)_2$	lake (filtered)	7.4	43	32 d	$NOEC_g$ $NOEC_g$ $NOEC_s$ $NOEC_s$	120 170 ≥ 120 ≥ 170	Spehar, 1986 [5,6]

(to be continued)

Table 1. *(continued)* Chronic toxicity of inorganic lead to freshwater organisms: NOEC values (underlined NOEC values: used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (ug Pb/l)	Reference
Fish *(continued)*										
Salmo gairdneri (fingerlings, 8 cm)	A(D)	F	$Pb(NO_3)_2$	well (filtered)	7.6-8.2	353	19 m	NOEC	18	Davies, 1976 [13,14]
	A(T)							NOEC	190	
	A(D)							NOEC	40	
	A(T)							NOEC	850	
	A(D)							$NOEC_g$	≥ 64	
	A(T)							$NOEC_g$	≥ 2,300	
Salmo gairdneri (sac fry, 25 mm)	D	F	$Pb(NO_3)_2$	tap (dechlor.)	6.7-7.3	28	19 m	NOEC	7	Davies, 1976 [13,15]
	A(T)							NOEC	7	
	D							NOEC	7	
	A(T)							NOEC	7	
	D							NOEC	≥ 62	
	A(T)							$NOEC_g$	≥ 62	
Salmo gairdneri (eyed eggs)	D	F	$Pb(NO_3)_2$	tap (dechlor.)	6.7-7.3	28	19 m	NOEC	8	Davies, 1976 [13,15]
	A(T)							NOEC	8	
	D							NOEC	27	
	A(T)							NOEC	27	
	D							$NOEC_g$	≥ 55	
	A(T)							$NOEC_g$	≥ 55	
Salmo gairdneri (sac fry)	A(T)	F	-	tap (filtered & dechlor.)	8.2	135	27 w	NOEC	28	Hodson, 1980 [10]
								$NOEC_{a,g}$	≥ 87	
Salmo gairdneri (eggs → juveniles)	A(T)	F	$Pb(NO_3)_2$	well	6.9-7.4	32-42	60 d	NOEC	71	Sauter, 1976 [1]
								$NOEC_g$	150	
								NOEC	250	
								$NOEC_h$	440	
Salmo gairdneri (underyearlings)	A(T)	F	$Pb(NO_3)_2$	tap (filtered & dechlor.)	7.7	135	32 w	NOEC	60	Hodson, 1978 [11]
								$NOEC_{a,g}$	120	
Salmo gairderi						geometric mean		NOEC	41	(n = 6)
Salmo salar (swim-up fry)	A	S	$Pb(NO_3)_2$	-	6.3	11	90 d	$NOEC_{a,g,d}$	20	Grande, 1983 [8]
Salvelinus fontinalis (life cycle; 3 generations)	A(D)	F	$Pb(NO_3)_2$	lake	6.8-7.6	44	3 yr	$NOEC_{a,s,g}$	39	Holcombe, 1976 [16]
	A(T)							$NOEC_{h,s,g}$	58	
	A(D)							$NOEC_{a,i}$	84	
	A(T)							$NOEC_{a,r}$	120	
Salvelinus namaycush	A(T)	F	$Pb(NO_3)_2$	well	7.0-7.3	25-38	60 d	NOEC	48	Sauter, 1976 [1]
								$NOEC_g$	200	
								$NOEC_{a,s}$	≥ 480	
Stizostedion vitreum	A(T)	F	$Pb(NO_3)_2$	well	6.7-7.1	32-45	30 d	$NOEC_{a,i}$	240	Sauter, 1976 [1]
								$NOEC_{g,h}$	400	

Abbreviations and footnotes Table 1

Toxicological endpoints
a = abnormalities (deformities): black tail; lordoscoliosis; atrophy of tail region
d = development
f = feeding rate
g = growth
h = hatching
r = reproduction
s = survival

Toxicity values (criterion)
NOEC = No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations) without effect.
NOEC (est.) = NOEC estimated from the LOEC, the Lowest-Observed-Effect-Concentration. (refers to two studies, see footnotes)

Toxicity values (result)
A = Actual (analysed) Pb concentration in the test water (background concentration, Cb, is included)
(T) = Total Pb concentration analysed
(D) = Dissolved Pb concentration analysed
N = Nominal (added) Pb concentration in the test water (background concentration, Cb, not included)
≥ = Unbounded NOEC (no effect was found at the highest test concentration)

Test conditions
F = Flow-through / continuous flow system
R = Renewal system
S = Static system
art. = artificial medium (reconstituted)
n.m. = nutrient medium (reconstituted)
Hardness = total hardness (calcium plus magnesium)

Analytical methods (see footnotes)
AAS = Atomic Absorption Spectrophotometry
ASV = Anodic Stripping Voltammetry
PP = Pulse Polarography

Footnotes

[1] Analysis with furnace-AAS in unfiltered water ((total Pb). The NOEC values derived from the different tests performed in this study all are (considerably) lower than the concentration of 1,000 ug/l at which precipitation of Pb was found. In a number of the tests, the occurrence of the abnormality scoliosis' (see further footnote [13]) was only indicated qualitatively; in the other tests the percentage affected animals was given.

[2] NOEC = TT ('Toxicity threshold'). The TT (TGK: 'Toxische Grenzkonzentration') is defined by Bringmann and co-workers as the concentration resulting in 3%-5% inhibition. The limit of 3% or 5% depends on the specific test (Bringmann and co-workers developed several tests, with different organisms).

[3] Continuous illumination.

[4] The NOEC for endpoint survival was not reported, but in all tests with the metals tested (Pb, As, Cd, Cr, Cu, and Hg, respectively), reproduction was reported to be a more sensitive endpoint than survival, except in the test with Cr.

[5] Analysis in unfiltered water ('acid-exchangeable' fraction: total Pb) and in 0.45 um Millipore filtered water (dissolved Pb); no data on analytical method. The dissolved fraction averaged 75%.

[6] The NOEC for endpoint survival was not reported. but in all tests with the metals tested (Pb, As, Cd, Cr, Cu, and Hg, respectively), growth was reported to be a more sensitive endpoint than survival (or both endpoints were equally sensitive).

[7] NOEC estimated from the LOEC (16% inhibition of reproduction at 30 ug/l): NOEC = LOEC/2.

[8] From Mance (1987), secondary reference; the original reference was not evaluated.

[9] Test started with exponentially growing populations. NOEC = EC10 for endpoint 'yield' (maximum number of animals); the EC10 was reported by the study authors.

[10] Analysis with AAS (total Pb). Abnormalities: 'black tail' and 'lordoscoliosis' (see further footnote [13]). At 29 en 97 ug/l (actual concentrations) the ALAD activity in erythrocytes was inhibited, but there was no effect on other haematological parameters (haematocrite, iron content, number and volume of erythrocytes).

[11] No data on the treatment of water samples before analysis or on the analytical method used. The results are considered to be for total Pb, since the actual concentrations are somewhat higher than the nominal concentrations. Moreover, the actual concentrations were compared by the study authors with water quality objectives for total Pb. Abnormality: 'black tail' (see further footnote [13]). The endpoints growth (length) was also studied, but no results on this endpoint were given. Hence it is assumed that growth was not affected. All test concentrations (13 to 120 ug/l; actual concentrations) resulted in effects on haematological parameters (decreased iron content and ALAD activity in erythrocytes; increased number of erythrocytes).

[12] NOEC estimated from the LOEC (19% inhibition of growth at 1000 µg/l): NOEC = LOEC/2.

[13] Abnormalities: starting with 'black tail' which at continuous exposure is followed by 'caudal fin erosion' (associated with haemorrhage) and 'lordoscoliosis' spinal curvatures). Two forms of spinal curvatures were observed, lordosis (dorsal-ventral spinal flexures) and scoliosis (bi-lateral spinal flexures); generally a combination of both effects was found. In severe cases of lordoscoliosis, paralysis and muscular atrophy of the flexed portion of the fish body occurred. Fish severely affected by lordoscoliosis will not be able to spawn.
According to the study authors, these abnormalities were most probably related to direct neurological damage (Pb also causes neurological effects in mammals). Lordoscoliosis may also have been caused by Pb induced metabolic changes (resulting in vitamin C and/or tryptophan deficiencies). Black tails and lordoscoliosis in *Salmo gairdneri* (rainbow trout) have also been reported to occur with whirling disease infections and parasitic infections, but pathological examinations of affected fiskh showed no indications of infections.

[14] Analysis with AAS (total Pb) and PP (dissolved Pb), after precipitation of insoluble lead complexes. The water was not acidified before analysis. Actual test concentrations: 100, 190, 380, 850 en 2,310 µg/l (total Pb) and 10, 18, 32, 41 and 64 µg/l dissolved Pb, respectively, resulting in a dissolved-Pb fraction of 3% tot 10%.

[15] Analysis with AAS (total Pb), after extraction of Pb (method according to Fishman & Midgett, 1968). However, since the test water has a low hardness, it was assumed by the study authors that all lead in the water was dissolved. Hence, the dissolved concentrations were set equal to the total concentrations measured.

[16] Analysis with AAS in pH 2.5-3 acidified water (total Pb) and in not acidified water (dissolved Pb), after extraction of Pb. Actual test concentrations: 34, 58, 19, 235 en 474 µg/l (total Pb) and 21, 39, 84, 176 and 383 µg/l (dissolved Pb), respectively, resulting in a dissolved-Pb fraction of 60% tot 80%. Total-Pb concentrations were also determined with ASV, after acid destruction, and with furnace AAS. Abnormalities: 'scoliosis' and 'black tail' (see further footnote [13]). The test was performed in UV-sterilised Lake Superior water.

Table 2. Chronic toxicity of inorganic lead to freshwater organisms: additional data (LC, EC, and NOEC values, not used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (µg Pb/l)	Reference
Algae (unicellular)										
Anacystis nidulans	N	S	$Pb(NO_3)_2$	n.m. (no EDTA)	6.9	-	2 w	$NOEC_g$	50,000	Lee, 1992 [3]
Anacystis nidulans	N	S	$Pb(NO_3)_2$	n.m. (+ EDTA)	5.4	-	2 w	$NOEC_n$	200,000	Lee, 1992 [3]
Chlorella sp.	N	S	$PbCl_2$	n.m. (low P)	6.2	-	7 d	EC_g (57%)	500	Monahan, 1976
Chlorella saccharaphila	A	-	$PbCl_2$	-	-	-	4-10 d	EC50	64,000	Rachlin, 1982 [2,4]
Navicula incerta	N	S	$PbCl_2$	n.m. (no chelator)	8.3	5	4 d	$EC50_g$	11,000	Rachlin, 1983
Nostoc muscorum	-	-	$PbCl_2$	-	-	-	15 d	$EC_{0.1}$	10,000	Rai, 1988 [1]
Scenedesmus sp.	N	S	$PbCl_2$	n.m. (low P)	6.2	27	7 d	EC_g (35%)	500	Monahan, 1976
Selenastrum sp.	N	S	$PbCl_2$	n.m. (low P)	6.2	27	7 d	EC_g (52%)	500	Monahan, 1976
Tetrahymena pyriformis	N	S	$Pb(NO_3)_2$	distilled water (+ $CaCO_3$)	-	20	4 d	$NOEC_r$	13,000	Carter, 1973
Tetrahymena pyriformis	N	S	$Pb(NO_3)_2$	distilled water (+ $CaCO_3$)	-	400	4 d	$NOEC_r$	158,000	Carter, 1973
Algae (multicellular)										
Cladophora glomerata (1 cm fragments)	N	S	-	n.m. (+ EDTA)	8.4	≥35	3 d	$NOEC_g$	700	Whitton, 1967
Plants										
Elodea canadensis	-	-	$Pb(CH_3COO)_2$	n.m. (+ sediment)	6.7	-	28 d	$EC50_g$	136,000	Brown, 1979
Lemna minor	-	-	$Pb(CH_3COO)_2$	n.m.	6.7	-	14 d	$EC50_g$	16,000	Brown, 1979
Myriophyllum spicatum	N	-	-	tap (+$FeSiO_3$)	-	-	32 d	$EC50_n$	363,000	Stanley, 1974
Molluscs										
Physa integra (adults)	A(T)	F	$Pb(NO_3)_2$	lake	7.1-7.7	46	28 d	$NOEC_r$	≥ 570	Spehar, 1978
Crustaceans										
Austropotamobius pallipes	A	F	$PbCl_2$	lake	6.7-7.3	-	30 d	LC50	1,500	Boutet, 1973 [5]
Austropotamobius pallipes	A	F	$PbCl_2$	lake	6.7-7.3	-	30 d	LC50	900	Boutet, 1973
Caridina rajadhari	N	R (1 d)	$Pb(NO_3)_2$	-	-	-	10 d	EC_o	207,000	Chinnaya, 1971
Ceriodaphnia dubia (P < 1d → F; (life cycle)	A(D) A(T)	R	$Pb(NO_3)_2$	river (110 µm filtered)	8.2	100	7 d	$EC50_r$ $EC50_r$	200 270	Spehar, 1986
Daphnia magna (P → F; (life cycle)	-	-	$Pb(NO_3)_2$	-	-	52 102 151	- - -	NOEC NOEC NOEC	9 78 85	Chapman, manuscript [2,4]

(to be continued)

Table 2. *(continued)* Chronic toxicity of inorganic lead to freshwater organisms: additional data (LC, EC, and NOEC values, not used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (ug Pb/l)	Reference
Crustaceans *(continued)*										
Daphnia magna P <1 d → F; (life cycle)	A	R	$Pb(NO_3)_2$	lake (25 um filtered)	8.1	225	21 d	LC50	1,800	Enserink, 1991
Daphnia magna (population)	A	F	$Pb(NO_3)_2$	lake (25 um filtered)	8.1	225	17 d	$EC50_{t,a}$	1,700	Enserink, 1991
Daphnia magna (life cycle)	-	-	$PbCl_2$	-	-	-	21 d	$EC_{r,a}$	30	Skidmore 1983 [1]
Daphnia sp.	N	S	$Pb(NO_3)_2$	river (sterile)	7.5-7.8	84	21 d	$NOEC_a$	2,500	Bringman, 1959b
Gammarus pseudolimnaeus (adults)	A(T)	F	$Pb(NO_3)_2$	lake	7.1-7.7	46	28 d	LC50	28	Spehar, 1978
Hyalella azteca	N	S	-	n.m. (high P)	6	-	5 d	LC (25%)	110	Freedman, 1980
Orconectes limosus	A	F	$PbCl_2$	lake	6.7-7.3	-	30 d	LC50	1,700	Boutet, 1973 [5]
Orconectes limosus	A	F	$PbCl_2$	lake	6.7-7.3	-	30 d	LC50	900	Boutet, 1973
Orconectes virilis	N	R (5 d)	$Pb(CH_3COO)_2$	-	-	-	40 d	EC_{vr}	500	Anderson, 1978 [4]
Insects										
Brachycentrus sp. (larvae)	A(T)	F	$Pb(NO_3)_2$	lake	7.1-7.7	46	28 d	$NOEC_a$	≥ 570	Spehar, 1978
Ephemerella grandis (larvae)	A	F	$Pb(NO_3)_2$	-	7.1	50	14 d	LC50	3,500	Nehring, 1976
Ephemerella subvaria	A	S	$PbSO_4$	tap (filtered)	7.3	44	7 d	LC50	16,000	Warnick, 1969
Hydropsyche bettini	A	S	$PbSO_4$	tap (filtered)	7.3	44	7 d	LC50	32,000	Warnick, 1969
Pteronarcys dorsata (larvae)	A(T)	F	$Pb(NO_3)_2$	lake	7.1-7.7	46	28 d	$NOEC_a$	≥ 570	Spehar, 1978
Pteronarcys californica (larvae)	A	F	$Pb(NO_3)_2$	-	7.1	-	14 d	LC50	≥ 19,000	Nehring, 1976
Tanytarsus dissimilis (larvae)	A(T)	S	$Pb(NO_3)_2$	lake	7.5	47	10 d	LC50	260	Anderson, 1980
Fish										
Anabas testudineus (mature)	N	R (1 d)	$Pb(NO_3)_2$	-	-	-	30 d	EC_1	1,300	Tulasi, 1989 [10]
Anguilla anguilla (50 g)	N	R (1 w)	$Pb(NO_3)_2$	tap	-	-	30 d	$NOEC_a$	≥ 300	Santos, 1990 [9]
Brachydanio rerio (eggs (up to blastula stage)	A(T)	R (1 d)	$Pb(NO_3)_2$	distilled water	-	2	3-5 d	EC_h	36	Ozoh, 1979 [6]
Lebiscus reticularis (< 2 d old)	N	R	$Pb(NO_3)_2$	-	8	80	3 m	$EC_{a,g}$	1,250	Crandall, 1962

(to be continued)

Table 2. Chronic toxicity of inorganic lead to freshwater organisms: additional data *(continued)* (LC, EC, and NOEC values, not used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Hardness (mg/l, as $CaCO_3$)	Exp. time	Criterion	Result (ug Pb/l)	Reference
Fish *(continued)*										
Oreochromis mossambicus	-	R (1 d)	$Pb(CH_3COO)_2$	-	8.2	210	21 d	$NOEC_{a}$	≥ 33,000	Ruparelia, 1989
Pimephales promelas (juveniles)	A(D) A(T)	F	$Pb(NO_3)_2$	lake (filtered)	7.4	43	32 d	EC_{g} $EC_{?}$	250 330	Spehar, 1986
Pimephales promelas (juveniles)	A(T)	R (50% per d)	$Pb(CH_3COO)_2$	art.	7.5	115	28 d	$NOEC_{a}$	≥ 1,000	Weber, 1991 [12]
Salmo gairdneri (underyearlings)	A(T)	F	$Pb(NO_3)_2$	tap (filtered)	7.7	135	21 d	LC50	2,400	Hodson, 1978
Salmo gairdneri (eggs → larvae)	-	-	$PbCl_2$	-	-	101	28 d	$NOEC_{a,d}$	10	Birge, 1981 [2]
Salmo gairdneri	-	-	$PbCl_2$	-	-	101	28 d	$EC50_{a,t}$	220	Birge, 1981 [2]
Salmo gairdneri (fingerlings)	D A(T)	F	$Pb(NO_3)_2$	tap (dechlor.)	6.9	30	14 d 14 d	LC50 LC50	200 200	Davies, 1976 [7]
Salmo gairdneri (P adults → F_1 fry)	A(D)	F	$Pb(NO_3)_2$	tap (dechlor.)	6.7-7.3	28	>9 m.	$NOEC_{t,h,a}$	≥ 27	Davies, 1976 [8]
Salmo gairdneri (sac fry)	A	F	$Pb(NO_3)_2$	well	8.0	385	14 w	EC_{a} (66%-85%)	540	Hodson 1982 [13]
Salmo trutta (yolk sac fry)	A	F	$Pb(NO_3)_2$	art. (filtered & deionised)	4.5	4	4 w	LC (100%)	12	Reader, 1989
Salmo trutta (yolk sac fry)	A	F	$Pb(NO_3)_2$	art. (filtered & deionised)	6.5	4	4 w	$NOEC_{a,g}$	≥ 13	Reader, 1989
Salmo trutta (yolk sac fry)	A	F	$Pb(NO_3)_2$	art. (filtered & deionised)	4.5	4	4 w	LC (90%)	2.4	Sayer, 1989
Salmo trutta (yolk sac fry)	A	F	$Pb(NO_3)_2$	art. (filtered & deionised)	4.5	4	4 w	$NOEC_{a,g}$	≥ 10	Sayer, 1989
Amphibians										
Ambystoma opacum (embryos → larvae)	-	-	$PbCl_2$	-	-	99	8 d	$EC50_{e,d}$	1,500	Birge, 1978 [2]
Bufo arenarum embryos (2-cell stage)	N	R	$Pb(NO_3)_2$	n.m.	-	-	3 d	$NOEC_{a,d}$	120	Pérez-Coll et al., 1988
Bufo arenarum (larvae)	N	S	-	n.m.	-	-	5 d	LC (40%)	8,000	Herkovits, 1991
Gastrophyne carolinesis (embryos → larvae)	-	F	$PbCl_2$	-	-	195	7 d	$EC50_{a,d}$	10	Birge, 1978 [2]
Rana catesbeinana (larvae)	N	R (1 d)	$Pb(NO_3)_2$	tap (filtered & dechlor.)	7,2	340	6 d	$NOEC_{a}$	≥ 1,000	Stricker-Shaw, 1991 [11]
Rana clamitans (larvae)	N	R (1 d)	$Pb(NO_3)_2$	tap (filtered & dechlor.)	7,2	340	6 d	$NOEC_{a}$	≥ 750	Strickler-Shaw, 1990 [11]
Rana clamitans (larvae)	N	R (1 d)	$Pb(NO_3)_2$	tap (filtered & dechlor.)	7,2	340	6 d	$NOEC_{a}$	≥ 1,000	Taylor, 1990 [11]
Rana pipiens (adults)	N	R (1 d)	$Pb(NO_3)_2$	-	-	-	30 d	LC50	10,500	Kaplan, 1967

Abbreviations and footnotes Table 2

Toxicological endpoints

d = development
g = growth
h = hatching
o = oxygen consumption
r = reproduction
s = survival
v = visual damage
vr = ventilation rate

Toxicity values (criterion)

NOEC	= No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations without effect.
EC	= Effect Concentration.
LC	= Lethal Concentration.
EC50 and LC50	= Median Effect Concentration and Median Lethal Concentration, i.e. the concentration which is calculated from a series of test concentrations to affect 50% of the organisms exposed to that concentration.
EC(x%) or LC(x%)	= At the given test concentration, x% effect was found compared to the control (e.g. EC$_{x}$ (35%) or LC (100%).

Toxicity values (result)

A	= Actual (analysed) Pb concentration in the test water (background concentration, Cb, is included)
(T)	= Total-Pb concentration analysed
(D)	= Dissolved-Pb concentration analysed)
N	= Nominal (added) Pb concentration in the test water (background concentration, Cb, not included)
≥	= Unbounded NOEC (no effect was found at the highest test concentration)

Test conditions

F	= Flow-through / continuous flow system
R	= Renewal system
S	= Static system
art.	= artificial medium (reconstituted)
n.m.	= nutrient medium (reconstituted)
Hardness	= total hardness (calcium plus magnesium)

Footnotes

[1] From Van de Meent et al. (1990), secondary reference; the original reference was not evaluated.

[2] From EPA (1984), secondary reference; the original reference was not evaluated.

[3] Continuous illumination.

[4] No data on toxicological endpoint(s).

[5] No feeding during the test.

[6] Alkalinity given instead of hardness

[7] Analysis of total Pb with AAS (atomic absorption spectrophotometry. However, since the test water has a low hardness, it was assumed by the study authors that all lead in the water was dissolved. Hence, the dissolved concencentrations were set equal to the total concentrations.

[8] P generation (adults) exposed for 9 months to dissolved-Pb concentrations up to 27 ug/l (analysis with PP: pulse polarography)and the F_1 generation (eggs to fry) exposed to total-Pb concentrations up to 95 ug/l (analysis with AAS: atomic absorption spectrophotometry). According to the study authors there was no effect on reproduction, hatching or survival of the fry (no quantitative data were reported on these endpoints, nor data on the exposure time of the F_1 generation). Since the test water had a low hardness it is assumed that the F generation was exposed to dissolved-Pb concentrations up to 95 ug/l (see also footnote [7]).

[9] Haematological parameters: significantly increased lactate content and number of lymphocytes; no effect on the other parameters studied (including the number of erythrocytes and the haemoglobin content).

[10] Reproduction (fertility) parameters: relative ovary weight and number of eggs.

[11] Exposure to sublethal concentrations of 300 of 750 ug/l resulted in effects on acquisition learning and retention (memory).

[12] Feeding behaviour (prey: water fleas) was significantly affected at ≥ 500 ug/l. The whole brain contents of the neurotransmitters serotonin and norepinephrine were significantly increased at 1,000 u/l. Faeces and surplus food were daily removed from the test water. At the total-Pb concentrations of 500 and 1,000 ug/l, around 25% was 'dissolved', based on measurements after filtration through a 2 µm filter. (Note: the dissolved fraction of metals is usually measured after filtration through a 0.45 µm filter)

[13] Analysis with atomic absorption spectrophotometry (AAS); no data on the treatment of the water before analysis. At termination the percentage of animals with the abnormality 'black tail' was 82%, 85% en 66%, depending on the quantity of food.

Table 3. Chronic toxicity of inorganic lead to saltwater organisms: NOEC values (underlined NOEC values: used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Salinity (°/oo)	Exp. time	Criterion	Result (ug Pb/l)	Reference
Algae										
Asterionella japonica	N	S	$Pb(NO_3)_2$	sea (0.22 um filtered, no EDTA)	-	30	3 d	$NOEC_g$	60	Fisher, 1981
Champia parvula	A	R (d 7-11)	$Pb(NO_3)_2$	sea (sterile, + EDTA)	-	30	14 d	$NOEC_r$	9	Steele, 1983
Protozoans										
Cristigera sp.	N	S	$Pb(NO_3)_2$	sea (sterile)	-	34	12 h	$NOEC_p$	150	Gray, 1973
Coelenterates										
Eirene viridula	N	R (2 d)	$Pb(NO_3)_2$	-	8.0	30	3 m	$NOEC_g$	300	Karbe, 1972
Annelids										
Ctenodrilus serratus	N	S	$Pb(CH_3COO)_2$	sea (filtered)	7.8	-	21 d	$NOEC_r$	500	Reish, 1978
Ophryotrocha diadema	N	S	$Pb(CH_3COO)_2$	sea (filtered)	7.8	-	21 d	$NOEC_r$	1,000	Reish, 1978
Molluscs										
Crassostrea virginea	-	-	-	-	-	-	20 w	$NOEC_s$	200	Eisler, 1977a [1]
Mercenaria mercenaria	-	-	-	-	-	-	20 w	$NOEC_s$	200	Eisler, 1977a [1]
Crustaceans										
Artemia salina (larvae)	N	R (2 d)	$Pb(NO_3)_2$	sea	>7.9	-	10 d	$NOEC_g$	1,000	Brown, 1971
Cancer anthonyi (embryos → larvae)	N	R (2 d)	$Pb(NO_3)_2$	sea (filtered)	7.8	34	11 d	$NOEC_s$	10	MacDonald, 1988
Mysidopsis bahia (life cycle)	A(T)	F	$Pb(NO_3)_2$	zee (filtered)	-	30	44 d	$NOEC_r$	17	Lussier, 1985
Rhithropanopeus harrissii (larvae)	-	R (1 d)	$PbCl_2$	sea (filtered)	-	20	> 14 d	$NOEC_d$	50	Benijts Claus, 1975

Abbreviations and footnotes Table 3

Toxicological endpoints
d = development
e = embryonic development
g = growth
p = population density
r = reproduction
s = survival

Toxicity values (criterion)
NOEC = No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations) without effect.

Toxicity values (result)
A = Actual (analysed) Pb concentration in the test water (background concentration, Cb, is included)
(T) = Total-Pb concentration analysed
N = Nominal (added) concentration in the test water (background concentration, Cb, not included)

Test conditions
F = Flow-through / continuous flow system
R = Renewal system
S = Static system
n.m. = nutrient medium (reconstituted)

Footnotes
[1] From Eisler (1977b), secondary referenc; the original reference, Eisler (1977a), was not evaluated.

Table 4. Chronic toxicity of inorganic lead to saltwater organisms: additional data (LC, EC, and NOEC values, not used for deriving risk limits in water)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Salinity (°/₀₀)	Exp. time	Criterion	Result (μg Pb/l)	Reference
Bacteria										
Pseudomonas marina	N	S	$PbCl_2$	sea. (art.)	7.6	-	-	$EC50_g$	43,000	Chan, 1988
Algae										
Asterionella japonica	N	S	$Pb(NO_3)_2$	sea 0,22 μm filtered; no EDTA	-	30	3 d	$EC50_g$	210	Fisher, 1981
Chlorella stigmatophora	N	S	$Pb(CH_3COO)_2$	sea (art.)	-	28	21 d	$EC50_g$	700	Christensen, 1979
Ditylum brightwellii	N N(D)	S	$PbCl_2$	n.m. + sea (+ 67 μM EDTA)	8.0	-	5 d	$EC50_g$	40 1.3	Canterford, 1980 [3]
Ditylum brightwellii	N) N(D)	S	$PbCl_2$	n.m. + sea (+ 260 μM EDTA)	8.0	-	5 d	$EC50_g$	400 1.0	Canterford, 1980 [3]
Dunaliella salina	N	S	$Pb(NO_3)_2$	sea (art.)	-	-	31 d	EC_g	300	Pace, 1977
Fucus serratus	-	-	$Pb(CH_3COO)_2$	-	-	-	-	EC (45%)	810	Stromgren, 1980 [1, 2]
Laminaria digitata	-	-	-	-	-	-	31 d	EC_g (50%-60%)	1,000	Bryan, 1976 [1]
Minutoxellus polymorphus	N	S	$PbCl_2$	n.m.	8.0	36	2 d	$EC50_g$	63	Walsh, 1988
Platymonas subcordiformis	A	S	$PbCl_2$	sea (enriched)	8.1	-	2 d	EC_g (48%)	2,500	Hessler, 1974
Skeletonema costatum	N	S	$Pb(NO_3)_2$	sea (art.) (enriched; + EDTA)	8.0	-	12 d	$NOEC_g$ $EC50_g$	0.1 5.1	Rivkin, 1979 [4]
Skeletonema costatum	N	S	$PbCl_2$	n.m.	8.0	36	2 d	$EC50_g$	20	Walsh, 1988
Annelids										
Capitella capitella (adults)	N	S	$Pb(CH_3COO)_2$	sea	7.8	-	28 d	LC50	1,000	Reish, 1976
Neanthes arenaceodentata (adults)	N	S	$Pb(CH_3COO)_2$	sea	7.8	-	28 d	LC50	3,200	Reish, 1976
Neanthes arenaceodentata (juveniles)	N	S	$Pb(CH_3COO)_2$	sea	7.8	-	28 d	LC50	2,500	Reish, 1976
Ophryotrocha labronica	N	R (2 d)	$Pb(NO_3)_2$	sea	>7.9	-	8 d	$NOEC_g$	≥ 10,000	Brown, 1971
Molluscs										
Mya arenaria	N	S	$Pb(NO_3)_2$	sea	8.0	30	7 d	$NOEC_g$	5,000	Eisler, 1977b
Mytilus edulis (2-3 cm)	N	F	$Pb(CH_3COO)_2$	sea	-	33	8 d	$NOEC_g$	≥ 200	Strömgren, 1982
Mytilus edulis	N	R	$PbCl_2$	sea	-	-	37 d	LC50	30,000	Talbot, 1976
Mytilus edulis	N	R	$Pb(NO_3)_2$	sea & tap	-	23	150 d	LC50	500	Schulzer-Baldes, 1972
Fish										
Fundulus heteroclitus (eggs → larvae)	N	S	$Pb(NO_3)_2$	sea- (filtered)	-	-	-	EC_s	1,000	Weis, 1977

Abbreviations and footnotes Table 4

Toxicological endpoints

e = embryonic development
g = growth
m = motility
s = survival

Toxicity values (criterion)

NOEC = No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations) without effect.
EC = Effect Concentration.
LC = Lethal Concentration.
EC50 and LC50 = Median Effect Concentration and Median Lethal Concentration, i.e. the concentration which is calculated from a series of test concentrations to affect 50% of the organisms exposed to that concentration.
EC(x%) = At the given test concentration x% effect was found compared to the control, e.g. EC (45%).

Toxicity values (result)

N = Nominal (added) Pb concentration in the test water (background concentration, Cb, not included)
(D) = Dissolved-Pb concentration, see further footnote [3].
A = Actual (analysed) Pb concentration in the test water (background concentration, Cb, is included)
≥ = Unbounded NOEC (no effect was found at the highest test concentration)

Test conditions

F = Flow-through / continuous flow system
R = Renewal system
S = Static system
art. = artificial medium (reconstituted)
n.m. = nutrient medium (reconstituted)

Footnotes

[1] From EPA (1984), secondary reference; the original reference was not evaluated.

[2] No data on toxicological endpoint(s).

[3] In this study the dissolved-Pb concentration was not measured, but calculated from the nominal concentration.

[4] Five tests were performed in this study, two with clone 'a' and three with clone 'b'. Growth parameters: exponential growth rate (duplication time of the number of cells), chlorophyl-a content, organic carbon content, protein content (per ml medium and per cell), cell size (um) and cell volume (um³). Nominal test concentrations: 0-0.05-0.5-5 ug/l or 0-0.1-1.0-10 ug/l. The NOEC of 0.1 µg/l and the EC50 of 3.1 ug/l (the latter being the arithmetic mean value of the five EC50 values for exponential growth, the most sensitive endpoint)are based on the results of all five tests.
Test medium: autoclaved artifial seawater (prepared with glass-distilled water), to which one-quarter of '*f* enrichment' was added. The medium included EDTA and vitamins.
The NOEC from this study was not used, because the reliability of the study is strongly questionable: the NOEC of 0.1 ug/l is 90-times lower than the next higher NOEC (9 ug/l, for the alga *Champia parvula*). Moreover, the very low test concentrations were not checked by analyses, the concentration-response relationship was not consistent and no statistical analyses were made.

Table 5. **Acute and chronic toxicity of alkyl lead to saltwater organisms: LC50, EC50 and NOEC values**

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Salinity (°/oo)	Exp. time	Criterion	Result (µg Pb/l)	Reference
Bacteria										
Bacteria (mix)	N	S	Et_4Pb	sea (filtered)	-	-	48 h	$EC50_n$ $NOEC_n$	200 80	Marchetti, 1978 [1]
Bacterien (mix)	N	S	Me_4Pb	sea (filtered)	-	-	48 h	$EC50_n$ $NOEC_n$	1,900 900	Marchetti, 1978 [1]
Algae (unicellular)										
Dunaliella tertiolecta	N	S	Et_4Pb	sea (filtered)	-	-	48 h	$EC50_{pn}$ $NOEC_{pn}$	150 100	Marchetti, 1978
Dunaliella tertiolecta	N	S	Me_4Pb	sea (filtered)	-	-	48 h	$EC50_{pn}$ $NOEC_{pn}$	1,700 450	Marchetti, 1978
Phaeodactylum tricornutum	A(T)	S	Et_4Pb	sea	-	35	6 h	$EC50_{pn}$	100	Maddock, 1980 [2]
Phaeodactylum tricornutum	A(T)	S	Me_4Pb	sea	-	35	6 h	$EC50_{pn}$	1,300	Maddock, 1980 [2]
Phaeodactylum tricornutum	A(T)	S	Et_3PbCl	sea	-	35	6 h	$EC50_{pn}$	100	Maddock, 1980 [2]
Phaeodactylum tricornutum	A(T)	S	Me_3PbCl	sea	-	35	6 h	$EC50_{pn}$	800	Maddock, 1980 [2]
Algae (multicellular)										
Chara vulgaris	A	S	Et_3PbCl	n.m.	-	-	14 d	$NOEC_g$	210	Heumann, 1987 [3]
Molluscs										
Mytilus edulis (6 cm, 28 g)	A(T)	F	Et_4Pb	sea	-	35	96 h	LC50	100	Maddock, 1980 [2]
Mytilus edulis (6 cm, 28 g)	A(T)	F	Me_4Pb	sea	-	35	96 h	LC50	270	Maddock, 1980 [2]
Mytilus edulis (6 cm, 28 g)	A(T)	R	Et_3PbCl	sea	-	35	96 h	LC50	1,100	Maddock, 1980 [2]
Mytilus edulis (6 cm, 28 g)	A(T)	R	Me_3PbCl	sea	-	35	96 h	LC50	500	Maddock, 1980 [2]
Crustaceans										
Arthemia salina (nauplii)	N	S	Et_4Pb	sea (filtered)	-	-	48 h	LC50 $NOEC_m$	85 25	Marchetti, 1978 [1]
Arthemia salina (nauplii)	N	S	Me_4Pb	sea (filtered)	-	-	48 h	LC50 $NOEC_m$	250 180	Marchetti, 1978 [1]
Crangon crangon (5 cm, 1 g)	A(T)	F	Et_4Pb	sea	-	35	96 h	LC50	20	Maddock, 1980 [2]
Crangon crangon (5 cm, 1 g)	A(T)	F	Me_4Pb	sea	-	35	96 h	LC50	110	Maddock, 1980 [2]
Crangon crangon (5 cm, 1 g)	A(T)	R	Et_3PbCl	sea	-	35	96 h	LC50	5,800	Maddock, 1980 [2]
Crangon crangon (5 cm, 1 g)	A(T)	R	Me_3PbCl	sea	-	35	96 h	LC50	8,800	Maddock, 1980 [2]

(to be continued)

Table 5. Acute and chronic toxicity of alkyllead to saltwater organisms: LC50, EC50 and NOEC values (continued)

Organism & life stage	A/N	Test type	Test substance	Test water	pH	Salinity (°/₀₀)	Exp. time	Criterion	Result (µg Pb/l)	Reference
Fish										
Morone labrax (larvae)	N	S	Et_4Pb	sea (filtered)	-	-	48 h	LC50 NOEC$_s$	65 10	Marchetti, 1978 [1]
Morone labrax (larvae)	N	S	Me_4Pb	sea (filtered)	-	-	48 h	LC50 NOEC$_s$	100 45	Marchetti, 1978 [1]
Pleuronectes platessa (5 cm, 3 g)	A(T)	F	Et_4Pb	sea	-	35	96 h	LC50	230	Maddock, 1980 [2]
Pleuronectes platessa (5 cm, 3 g)	A(T)	F	Me_4Pb	sea	-	35	96 h	LC50	50	Maddock, 1980 [2]
Pleuronectes platessa (5 cm, 3 g)	A(T)	R	Et_3PbCl	sea	-	35	96 h	LC50	1,700	Maddock, 1980 [2]
Pleuronectes platessa (5 cm, 3 g)	A(T)	R	Me_3PbCl	sea	-	35	96 h	LC50	24,600	Maddock, 1980 [2]
Pleuronectes platessa (5 cm, 3 g)	A(T)	R	Et_2PbCl_2	sea	-	35	96 h	LC50	75,000	Maddock, 1980 [2]
Pleuronectes platessa (5 cm, 3 g)	A(T)	R	Me_2PbCl_2	sea	-	35	96 h	LC50	300,000	Maddock, 1980 [2]

Abbreviations and footnotes Table 5

Alkyl lead compounds
Et_4Pb = Tetraethyl lead
Me_4Pb = Tetramethyl lead
Et_3PbCl = Triethyl lead chloride
Me_3PbCl = Trimethyl lead chloride
Et_2PbCl_2 = Diethyl lead dichloride
Me_2PbCl_2 = Dimethyl lead dichloride

Toxicological endpoints
g = growth
ph = photosynthetic activity (incorporation of ^{14}C)
s = survival

Toxicity values (criterion)
EC50 and LC50 = Median Effect Concentration and Median Lethal Concentration, i.e. the concentration which is calculated from a series of test concentrations to affect 50% of the organisms exposed to that concentration.
NOEC = No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations) without effect.

Toxicity values (result)
A = Actual (analysed) Pb concentration in the test water
(T) = Total Pb concentration analysed
N = Nominal (added)) Pb concentration in the test water

Test conditions
F = Flow-through / continuous flow system
R = Renewal system
S = Static system
n.m. = nutrient medium (reconstituted)

Footnotes

(1) Test performed in the dark.

(2) Purity test compounds: 98%, with the exception of tetramethyl lead (Me_4Pb), which was tested as an anti knock formulation containing dibromoethane(DBE) and dichloroethane (DCE) in addition to Me_4Pb. The Me_4Pb : DBE ratio in the test water was around 1:4 and the Me_4Pb : DCE ratio was 1:10. Based on a comparison of the DBE and DCE concentrations in the test water with acute toxicity data for these compounds, the study authors concluded that DBE and DCE did not materially attribute to the toxicity found in the tests with the tetramethyl lead formulation. The DBE concentration was always <2 mg/l and that of DCE <5 mg/l.

(3) A comparative test with inorganic lead, added as $Pb(NO_3)_2$, resulted in a 10-times higher NOEC for *Chara vulgaris* (see Table 1).

APPENDIX II

ECOTOXICITY - TERRESTRIAL ORGANISMS

(Tables 6 to 9)

Table 6. Toxicity of inorganic lead to soil microbe-mediated processes: NOEC values (underlined NOEC values: used for deriving risk limits in soil)

Toxicological endpoint	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	NOEC in test soil (mg Pb/kg d.w.)		NOEC in standard soil [2] (mg Pb/kg d.w.)	Reference
C-mineralization											
Respiration	$PbCl_2$	sand Cb: 32 mg/kg (CEC = 1.5)	7.7	1.6	2	70 w	NOEC	150	N	240	Doelman, 1984a [4,6,7]
Respiration	$PbCl_2$	sandy loam Cb: 13 mg/kg (CEC = 11)	5.1	6	9	43 w	NOEC	150	N	200	Doelman, 1984a [7]
Respiration	$PbCl_2$	silty loam Cb: 42 mg/kg (CEC = 16)	7.4	3	19	90 w	NOEC	1,000	N	1,200	Doelman, 1984a [7]
Respiration	$PbCl_2$	clay Cb: 130 mg/kg (CEC = 30)	6.8	3	60	80 w	NOEC	3,000	N	2,300	Doelman, 1984a [5,7]
Respiration	$PbCl_2$	sandy peat Cb: 26 mg/kg (CEC = 52)	4.3	13	5	82 w	NOEC	150	N	190	Doelman, 1984a [7]
Respiration	$Pb(NO_3)_2$	loamy sand Cb: 2 mg/kg	4.9	4	5	8 w	NOEC	10	N	15	Cornfield, 1977
Respiration	$PbCl_2$	silty loam Cb: 2 mg/kg	6.9	2	44	3 m	NOEC	27	N	24	Chang, 1981 [19]
Respiration	$Pb(NO_3)_2$	clay	6.7	2	>50[b]	14 d	NOEC	5,000	N	5,200	Mikkelsen, 1974 [5,7]
Respiration	$Pb(NO_3)_2$	sand	6.8	1-2	<5[b]	6 d	NOEC	1,000	N	1,500	Mikkelsen, 1974 [4,6,7]
Respiration	$PbCl_2$	litter Cb: 13 mg/kg	-	>30[a]	<5[a]	4 w	NOEC	≥ 1,000	N	1,000	Spalding, 1979 [3,6]
Respiration	PbO	sand Cb: 35 mg/kg	6.0	4	5	5 m	NOEC[c]	333	N	480	Bhuiya, 1972 [26]
N-mineralization											
N-mineralization	$PbCl_2$	silty loam Cb: 2 mg/kg	6.9	2	44	3 m	NOEC	200	N	180	Chang, 1982 [18]
N-mineralization	$Pb(CH_3COO)_2$	loam	5.8	4	23	3 w	NOEC[e]	517	N	570	Liang, 1977 [22,23]
N-mineralization	$Pb(CH_3COO)_2$	silty clay	6.6	5	45	3 w	NOEC[e]	517	N	440	Liang, 1977 [22,24]
N-mineralization	$Pb(CH_3COO)_2$	clay loam	7.8	6	30	3 w	NOEC[e]	345	N	340	Liang, 1977 [22,25]
N-mineralization	$Pb(CH_3COO)_2$	silty clay	7.4	9	34	3 w	NOEC	1,035	N	950	Liang, 1977 [22]
Ammonification	PbO	sand Cb: 35 mg/kg	6-7	2	<5[b]	14 d	NOEC	1,000	N	1,500	Bhuiya, 1974 [6,7]
Nitrification	$Pb(CH_3COO)_2$	loam	5.8	4	23	10 d	NOEC[e]	345	N	380	Liang, 1978 [20,21]
Nitrification	$Pb(CH_3COO)_2$	clay loam	7.8	6	30	10 d	NOEC	1,035	N	1,000	Liang, 1978 [20]
Nitrification	$Pb(CH_3COO)_2$	silty clay	7.4	9	34	10 d	NOEC	1,035	N	950	Liang, 1978 [20]
Nitrification	PbO	sand Cb: 35 mg/kg	6-7	2	<5[b]	14 d	NOEC	1,000	N	1,500	Bhuiya, 1974 [6,7]

(to be continued)

Table 6. *(continued)* Toxicity of inorganic lead to soil microbe-mediated processes: NOEC values (underlined NOEC values: used for deriving risk limits in soil)

Toxicological endpoint	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	NOEC in test soil (mg Pb/kg d.w.)	NOEC in standard soil [2] (mg Pb/kg d.w.)	Reference
Mineralization of specific substrates										
Glucose	$Pb(NO_3)_2$	soil (CEC = 8)	5.0	<2[a]	9	16 d	NOEC	1,000	N <u>1,400</u>	Debosz, 1985 [4,7]
Cellulose (I)	$PbCl_2$	loamy sand Cb: 37 mg/kg	-	3[a]	18[a]	30 d	NOEC	100	N 120	Khan, 1984 [7]
Cellulose (II)	$PbCl_2$	loamy sand Cb: 50 mg/kg	-	3[a]	18[a]	30 d	NOEC	100	N 120	Khan, 1984 [7]
Cellulose (III)	PbO of $PbCO_3$	loamy sand Cb: 37 mg/kg	-	3[a]	18[a]	30 d	NOEC	1,000	N 1,200	Khan, 1984 [7]
Cellulose (I + II + III)					geometric mean		NOEC		N <u>260</u>	
Enzyme activities										
Amylase	$PbCl_2$	litter Cb = 13 mg/kg	-	>30[a]	<5[a]	4 w	NOEC	1,000	N <u>1,000</u>	Spalding, 1979 [3,6]
Cellulase	$PbCl_2$	litter Cb = 13 mg/kg	-	>30[a]	<5[a]	4 w	NOEC	≥ 1,000	N <u>1,000</u>	Spalding, 1979 [3,6]
Dehydrogenase	$PbCl_2$	sand	4.1	3	12	-	NOEC	375	N <u>490</u>	Doelman, 1979a [7]
Dehydrogenase	$PbCl_2$	clay	7.0	3	96	-	NOEC	≥ 7,500	N <u>6,200</u>	Doelman, 1979a [5, 7]
Dehydrogenase	$PbCl_2$	peat	5.6	46	3	-	NOEC	≥ 7,500	N <u>7,700</u>	Doelman, 1979a [3,6,7]
Phosphatase (acid) (I)	$Pb(CH_3COO)_2$	loam	5.8	4	23	0.5 h	NOEC	517	N 570	Juma, 1977
Phosphatase (acid) (II)	$Pb(NO_3)_2$	loam	5.8	4	23	0.5 h	NOEC	517	N 570	Juma, 1977
Phosphatase (acid) (I + II)					geometric mean		NOEC		N <u>570</u>	
Phosphatase (alkaline) (I)	$Pb(CH_3COO)_2$	silty clay	7.4	9	34	0.5 h	NOEC	517	N 470	Juma, 1977
Phosphatase (alkaline) (II)	$Pb(NO_3)_2$	silty clay	7.4	9	34	0.5 h	NOEC	517	N 470	Juma, 1977
Phosphatase (alkaline) (I + II)					geometric mean		NOEC		N <u>470</u>	
Urease (I)	$PbNO_3$	soil	6.5	4	31	5 h	NOEC	≥ 50	N 50	Bremner, 1971
Urease (II)	$PbCl_2$	soil	6.5	4	31	5 h	NOEC	≥ 50	N 50	Bremner, 1971
Urease (I + II)					geometric mean		NOEC		N <u>50</u>	
Urease (I)	$PbNO_3$	soil	7.3	5	31	5 h	NOEC	≥ 50	N 49	Bremner, 1971
Urease (II)	$PbCl_2$	soil	7.3	5	31	5 h	NOEC	≥ 50	N 49	Bremner, 1971
Urease (I + II)					geometric mean		NOEC		N <u>49</u>	
Urease (I)	$Pb(CH_3COO)_2$	silty loam	5.1	3	17	0.5 h	NOEC[e]	517	N 630	Tabatabai, 1977 [11]
Urease (II)	$Pb(NO_3)_2$	silty loam	5.1	3	17	0.5 h	NOEC	1,035	N 1,300	Tabatabai, 1977
Urease (I + II)					geometric mean		NOEC		N <u>900</u>	
Urease (I)	$Pb(CH_3COO)_2$	clay loam	7.8	6	30	0.5 h	NOEC	1,035	N 1,000	Tabatabai, 1977
Urease (II)	$Pb(NO_3)_2$	clay loam	7.8	6	30	0.5 h	NOEC[e]	345	N 340	Tabatabai, 1977 [12]
Urease					geometric mean		NOEC		N <u>580</u>	
Urease (I)	$Pb(CH_3COO)_2$	loam	5.8	4	23	0.5 h	NOEC[e]	517	N 570	Tabatabai, 1977 [13]
Urease (II)	$Pb(NO_3)_2$	loam	5.8	4	23	0.5 h	NOEC[e]	103	N 110	Tabatabai, 1977 [14]
Urease					geometric mean		NOEC		N <u>250</u>	

(to be continued)

Table 6. *(continued)* Toxicity of inorganic lead to soil microbe-mediated processes: NOEC values (underlined NOEC values: used for deriving risk limits in soil)

Toxicological endpoint	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	NOEC in test soil (mg Pb/kg d.w.)		NOEC in standard soil [2] (mg Pb/kg d.w.)	Reference
Enzyme activities (continued)											
Urease (I)	$Pb(CH_3COO)_2$	clay loam	7.8	6	30	0.5 h	NOEC	1,035	N	1,000	Tabatabai, 1977
Urease (II)	$Pb(NO_3)_2$	clay loam	7.8	6	30	0.5 h	NOEC	103	N	100	Tabatabai, 1977
Urease (I + II)					geomtric mean		NOEC		N	<u>320</u>	
Urease (I)	$Pb(CH_3COO)_2$	silty loam	6.8	7	42	0.5 h	NOEC	1,035	N	890	Tabatabai, 1977
Urease (II)	$Pb(NO_3)_2$	silty loam	6.8	7	42	0.5 h	NOEC	1,035	N	890	Tabatabai, 1977
Urease (I + II)					geometric mean		NOEC		N	<u>890</u>	
Urease (I)	$Pb(CH_3COO)_2$	silty clay	7.4	9	34	0.5 h	NOEC	103	N	94	Tabatabai, 1977
Urease (II)	$Pb(NO_3)_2$	silty clay	7.4	9	34	0.5 h	NOEC	103	N	94	Tabatabai, 1977
Urease (I + II)					geometric mean		NOEC		N	<u>94</u>	
Xylanase	$PbCl_2$	litter Cb: 13 mg/kg	-	>30[a]	<5[a]	4 w	NOEC	≥ 1,000	N	<u>1,000</u>	Spalding, 1979 [3,6]

Table 7. Chronic toxicity of inorganic lead to soil plants: NOEC values (underlined NOEC values: used for deriving risk limits in soil)

Organism	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	NOEC in test soil (mg Pb/kg d.w.)	NOEC in standard soil [2] (mg Pb/kg d.w.)	Reference
Avena sativa (oat)	$Pb(CH_3COO)_2$	loam Cb: 30 mg/kg (CEC = 15)	5.6	1.6	12	170 d	$NOEC_y$	≥ 800	N 1,100	De Haan, 1985 [4]
Avena sativa (oat)	$Pb(CH_3COO)_2$	loam Cb: 26 mg/kg (CEC = 21)	5.4	2	40	170 d	$NOEC_y$	≥ 800	N 740	De Haan, 1985
Avena sativa (oat)	$Pb(CH_3COO)_2$	loam Cb: 51 mg/kg (CEC = 33)	5.2	3	58	170 d	$NOEC_y$	≥ 800	N 610	De Haan, 1985 [5]
Avena sativa (oat)	$Pb(CH_3COO)_2$	sandy loam Cb: 16 mg/kg (CEC = 9)	5.0	3	4	170 d	$NOEC_y$	≥ 800	N 1,200	De Haan, 1985 [6]
Avena sativa (oat)	$Pb(CH_3COO)_2$	sandy loam Cb: 19 mg/kg (CEC = 19)	5.4	7	5	170 d	$NOEC_y$	≥ 800	N 1,100	De Haan, 1985
Avena sativa (oat)	$Pb(CH_3COO)_2$	sandy loam Cb: 43 mg/kg (CEC = 47)	4.5	19	4	170 d	$NOEC_y$	≥ 800	N 930	De Haan, 1985 [6]
Avena sativa (oat)	$PbCl_2$	loamy sand Cb: 50 mg/kg	-	3*	18*	42 d	$NOEC_g$	100	N 120	Khan, 1984 [7]
Avena sativa					geometric mean		$NOEC_{y,g}$		N 690	(n = 7)
Lolium perenne (rye-grass)	$Pb(CH_3COO)_2$	sandy loam Cb: 12 mg/kg ($CaCO_3$ added)	7.2	4	<5	6-8 w	$NOEC_y$	≥ 1,050	N 1,500	Dijkshoorn, 1979 [6]
Plantago lanceolata (plantain)	$Pb(CH_3COO)_2$	sandy loam Cb: 12 mg/kg ($CaCO_3$ added)	7.2	4	<5	6-8 w	$NOEC_y$	≥ 1,050	N 1,500	Dijkshoorn, 1979 [6]
Raphanus sativa (radish)	$PbCl_2$	loamy sand Cb: 50 mg/kg	5.4	3*	18*	42 d	$NOEC_g$	100	N 120	Khan, 1983 [7,27]
Trifolium repens (clover)	$Pb(CH_3COO)_2$	sandy loam Cb: 12 mg/kg ($CaCO_3$ added)	7.2	4	<5	6-8 w	$NOEC_y$	≥ 1,050	N 1,500	Dijkshoorn, 1979 [6]
Triticum aestivum (wheat)	$PbCl_2$	loamy sand Cb: 37 mg/kg	--	3*	18*	42 d	$NOEC_g$	100	N 120	Khan, 1984 [7]

Table 8. Chronic toxicity of inorganic lead to soil invertebrates: NOEC values (<u>underlined</u> NOEC values: used for deriving risk limits in soil)

Organism	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	NOEC in test soil (mg Pb/kg d.w.)		NOEC in standard soil [2] (mg Pb/kg d.w.)	Reference
<u>Oligochaetes</u>											
Dendrobaena rubida (earthworm)	$Pb(NO_3)_2$	sand + manure (1:2)mixture	6.5	10	5'	3 m	$NOEC_r$	560	Tα	740	Bengtsson, 1986 [7]
			5.5	10	5'	3 m	$NOEC_r$	564	Tα	740	
			4.5	10	5'	3 m	$NOEC_r$	130	Tα	170	
<u>Dendrobena rubida</u>						geometric mean	$NOEC_r$		Tα	<u>450</u>	(n = 3)
Eisenia foetida (earthworm)	$Pb(CH_3COO)_2$	<u>manure</u> + soil (2:3)	-	30'	<5'	8 w	$NOEC_r$	2,000	N	2,000	Malecki, 1982 [3,6, 15,16]
							$NOEC_g$	10,000	N		
Eisenia foetida (earthworm)	$Pb(CH_3COO)_2$	<u>manure</u> + soil (10:9)	-	>30'	<5'	20 w	$NOEC_r$	1,000	N	1,000	Malecki, 1982 [3,6, 15,17]
							$NOEC_g$	≥ 10,000	N		
<u>Eisenia foetida</u>						geometric mean	$NOEC_r$		N	<u>1,400</u>	(n = 2)
Lumbricus rubellus (earthworm)	$PbCl_2$	sandy clay	7.3	3	17	12 w	$NOEC_r$	200	Tα	<u>240</u>	Ma, 1982a [7]
<u>Gastropods</u>											
Arion ater (snail)	$Pb(NO_3)_2$	food (vegetables & fruit mixture)	-	>30'	<5'	27 d	$NOEC_{a,f,g,s}$	1,000	N	<u>1,000</u>	Marigomez, 1986 [3,6,10]
<u>Crustaceans</u>											
Porcellio scaber (woodlouse)	-	litter	-	>30'	<5'	-	NOEC	40	N	<u>40</u>	Capelleveen, 1985 [3,6,7]
<u>Insects</u>											
Onychiurus armatus (springtail)	$Pb(NO_3)_2$	food (fungi)	-	>30'	<5'	17 w	$NOEC_{r,g}$	1,100	Tα	<u>1,100</u>	Bengtsson, 1985 [3,6,7]
<u>Mites</u>											
Platynothrus peltifer	$Pb(NO_3)_2$	food (algae)	-	>30'	<5'	3 m	$NOEC_{g,i}$	430	Tα	<u>430</u>	Denneman, 1991 [3,6]
							$NOEC_s$	≥ 1,500	Tα		

Table 9. Chronic toxicity of inorganic lead to soil plants and invertebrates: additional data (EC and NOEC values, not used for deriving risk limits in soil)

Organism	Test substance	Soil type or substrate	pH	% OM [1]	% Clay	Exp. time	Criterion	Result in test soil (mg Pb/kg d.w.)		reference
Plants										
Medicago sativa (alfalfa)	$PbCl_2$	silty loam	7.2	-	-		$NOEC_g$	≥212	Tα?	Lagerwerff, 1973 [8,30]
Picea sitchensis (spruce)	$PbCl_2$	peat + sand (1:1)	3.3	>30[a]	<5[a]	100 d	$NOEC_n$ EC_m	40 34	Tα Tα	Burton, 1984 [3,6,7,27]
Raphanus sativa (radish)	$PbCl_2$ + PbO (1:1)	loamy sand Cb: 37 mg/kg	4.6	3[a]	18[a]	42 d	$NOEC_g$	500	N	Khan, 1983 [7,28]
Triticum aestivum (wheat)	$PbCO_3$	loamy sand Cb: 37 mg/kg	-	3[a]	18[a]	42 d	$NOEC_g$	1,000	N	Khan, 1984 [7,28]
Triticum aestivum (wheat)	PbO / $PbSO_4$	loamy sand Cb: 37 mg/kg	-	3[a]	18[a]	42 d	$NOEC_g$	≥ 1,000	N	Khan, 1984 [7,28]
Zea mays (corn)	$PbCl_2$	silty loam	7.2	-	-		$NOEC_g$	≥212	Tα?	Lagerwerff, 1973 [8,30]
Oligochaetes										
Eisenia foetida (earthworm)	$Pb(CH_3COO)_2$	manure + soil (2:3)	-	>30[a]	5[a]	6 w	EC_r	5,000	N	Neuhauser, 1984 [3,7]
Eisenia foetida (earthworm)	$Pb(CH_3COO)_2$	sludge + soil (1:1)	6.5-7	-	-	8 w	$NOEC_g$	≥ 36,000	N	Hartenstein, 1981 [9]
Eisenia foetida (earthworm)	$PbCO_3$	sludge + soil (1:1)	6.5-7	-	-	8 w	$NOEC_g$	≥ 51,000	N	Hartenstein, 1981 [9]
Lumbricus rubellus (earthworm)	$PbCl_2$	sandy loam	7.3	8	17	6-12 w	$NOEC_g$	1,000	N	Ma, 1982b [7,31]
Nematodes										
Mesorhabditis monhystera	$Pb(NO_3)_2$	food (agar/bacteria)	-	>30[a]	<5[a]	22 d	EC_p	7.6	Tα	Doelman, 1984b [3,6,7]
Aphelenchus avenae	$Pb(NO_3)_2$	food (agar/fungi)	-	>30[a]	<5[a]	21 d	EC_p	0.08	Tα	Doelman, 1984b [3,6,7]
Crustaceans										
Porcellio scaber (woodlouse)	PbO	litter	4.6	>30[a]	<5[a]	64 w	$NOEC_{g,r}$	6,400	Tα	Beyer, 1985 [3,6,29]
Porcellio scaber (woodlouse)	$Pb(NO_3)_2$	food (grass seeds)	-	>30[a]	<5[a]	>30 d	$NOEC_r$	16,000	Tα	Beeby, 1980 [3,6,29]

Abbreviations and footnotes Table 6 to Table 9

Toxicological endpoints

f = food consumption
g = growth
m = mycorrhiza formation
p = population growth
r = reproduction
s = survival
w = weight
y = yield

Toxicity values (criterion)

NOEC = No Observed Effect Concentration, i.e. the highest concentration (in a series of test concentrations) without effect.
NOEC* = NOEC estimated from the LOEC, the Lowest Observed Effect Concentration (refers to a number of microbial studies, see footnotes)
EC = Effect Concentration (No NOEC could be derived)

Toxicity values (result)

N = Nominal (added) Pb concentration in the test soil or substrate (background Pb concentration, Cb, not included)
T_α = Actual (analysed) Pb concentration in the test soil or substrate (background Pb concentration, Cb, included)
≥ = Unbounded NOEC (no effect was found at the highest test concentration)

Footnotes

[1] % OM = Organic matter content (dry weight percentage) in the soil or substrate. In a number of cases the %OM was estimated from the percentage organic carbon, as follows: %OM = 1,7 x % organic C (according to Denneman & Van Gestel, 1990).

In a number of cases the percentage clay was estimated from the cation exchange capacity (CEC) and the %OM, from CEC (meq./100 g soil) = (2.5 x %OM) + (0.5 x %clay) (according to Doelman & Haanstra, 1983).

In most earthworm tests the animals were exposed to clean soil covered with manure or sludge to which lead was added, without mixing the soil with the substrate. In those cases the %OM and %clay refer to the manure or sludge substrate, see also footnotes [9] and [15].

[2] S.B. = Standard soil. The NOEC determined in the test soil ($NOEC_{exp}$) has been converted to a 'normalised' NOEC in standard soil ($NOEC_{S.B}$), as follows:

$$NOEC_{S.B} = NOEC_{exp} \times \frac{85}{50 + \%OM + \%clay}$$

(85 mg/kg d.w. is the background concentration 'Cb' of lead in 'Dutch standard soil', defined as a soil containing 10% OM and 25% clay)

Note: Both for the organic matter content and the clay content a maximum and minimum value are used for normalisation (according to Denneman & Van Gestel, 1990), see foonotes [3] to [6].

[a] = The values (%OM and/or %clay) in the soil or substrate were not reported as such by the study authors, but estimated from other data reported (e.g. on soil texture).

[3] = The organic matter content is higher than the maximum value of 30% that is used for normalisation; a value of 30% has been used for the calculation of the $NOEC_{S.B}$.

[4] = The organic matter content is lower than the minimum value of 2% that is used for normalisation; a value of 2% has been used for the calculation of the $NOEC_{S.B}$.

[5] = The clay content is higher than the maximum value of 50% that is used for normalisation; a value of 50% was used for the calculation of the $NOEC_{S.B}$.

[6] = The clay content is lower than the minimum value of 5% that is used for normalisation; a value of 5% has been used for the calculation of the $NOEC_{S.B}$.

[7] = From Denneman & Van Gestel (1990), secondary reference; the original references were not evaluated. The report by Dennemann & Van Gestel (1990) includes the terrestrial ecotoxicity data on inorganic lead, that were used earlier in the Netherlands for deriving soil quality objectives.

[8] = From IPCS (1989), secondary reference; the original reference was not evaluated.

[9] = The earthworms were exposed to clean soil covered with sludge to which lead was added. The NOEC values refer to the Pb content in dry sludge. The NOEC values from these tests with *Eisenia foetida* (endpoint: growth) were not used since an 18- to 51-times lower NOEC for *E. foetida* was found for endpoint reproduction in two other tests (see Table 8: Malecki, 1982).

[10] = At termination a lower body weight was found at all exposure concentrations, but this effect was not dose-related.

[11] = NOEC estimated from the LOEC (17% inhibition at 1,035 mg/kg): NOEC = LOEC/2.

[12] = NOEC estimated from the LOEC (27% inhibition at 1,035 mg/kg): NOEC = LOEC/3.

[13] = NOEC estimated from the LOEC (11% inhibition at 1,035 mg/kg): NOEC = LOEC/2.

[14] = NOEC estimated from the LOEC (55% inhibition at 1,035 mg/kg): NOEC = LOEC/10.

[15] = Earthworms exposed to clean soil covered with manure to which lead was added. The NOEC values refer to the Pb content in dry manure..

[16] = Comparative tests with other lead compounds ($Pb(NO_3)_2$, $PbCO_3$, PbO, $PbSO_4$) resulted in a significant ($p < 0.05$) effect on reproduction at nonimal concentrations of 4,000 to 10,000 mg/kg and on growth at nominal concentrations of 12,000 to ≥ 40,000 mg/kg; NOEC values were not reported. Reproduction was the most sensitive endpoint in all tests. According to the ' materials and methods' section, survival was included in the study. but no results on this endpoint were reported. Based on the data on the 20-w test that was also conducted in this study, survival is a less sensitive endpoint than reproduction and growth (see also footnote [17]).

[17] = Test performed at sublethal test concentrations.

[18] = N-mineralization parameters: organic-N, inorganic-N and nitrate-N. Clay and organic matter content: estimated from Chang & Broadbent (1981), see footnote [19].

[19] = NOEC is EC10 (reported by the study authors: Chang & Broadbent, 1981).
Percentage OM estimated from % organic C; percentage clay estimated from %OM and CEC.

[20] = Percentage OM estimated from % organic C.

[21] = NOEC estimated from the LOEC (26% inhibition at 1,035 mg/kg): NOEC = LOEC/3.

[22] = N-mineralization parameters: ammonium-N, nitrite-N en nitrate-N.

[23] = NOEC estimated from the LOEC (17% inhibition at 1,035 mg/kg): NOEC = LOEC/2.

[24] = NOEC estimated from the LOEC (19% inhibition at 1,035 mg/kg): NOEC = LOEC/2.

[25] = NOEC estimated from the LOEC (28% inhibition at 1,035 mg/kg): NOEC = LOEC/3.

[26] = NOEC estimated from the LOEC (22% inhibition is 1,000 mg/kg): NOEC = EC/3.
The CO_2 production was measured during the last 3 months of the exposure period. In a comparative test in which the soil was mixed with 0.5% finely ground straw, respiration was hardly inhibited at 1,000 mg/kg.

[27] = NOEC, based on root growth; shoot growth was a less sensitive endpoint.
The NOEC value from this test was not used because of the very low pH value of the soil.

[28] = The NOEC values from these tests with *Triticum aestivum* (in which an 'insoluble' Pb compound was tested) were not used since a 10-times lower NOEC for *T. aestivum* was found in a comparative test (in which a soluble Pb compound was tested) in the same study (see Table 7).

[29] = The NOEC values from these tests with *Porcellio scaber* were not used since a 160- to 400-times lower NOEC for *P. scaber* was found in another test (see Table 8: Capelleveen, 1985).

[30] = The NOEC values from these tests were not used since normalisation to standard soil was not possible (no data on the organic matter and clay content of the soil).

[31] = The NOEC value from this test with *Lumbricus rubellus* (endpoint: growth) was not used since a 5-times lower NOEC for *L. rubricus* was found for endpoint reproduction in another test (see Table 8: Ma, 1982a).

APPENDIX III REFERENCES ECOTOXICOLOGICAL DATA ON LEAD

(Tables 1 to 9 of this report and additional data)

The additional references comprise data on the accumulation and toxicity of inorganic lead, lead metal (lead shot and sinkers) and alkyl lead in a variety of aquatic and terrestrial organisms, including birds, agricultural crops and livestock. Data from these additional references were included in the first draft of the "Integrated Criteria Document Lead" (ICDL), but not included in the final ICDL or in this report.

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Onderwerp
Aanbieding RIVM/CSR-rapport "Ecotoxicity of lead – Aquatic and terrestrial data"
(Addendum bij RIVM rapport 601014003: "Eval

Hierbij zend ik u RIVM/CSR rapport "Ecotoxicity of lead – Aquatic and terrestrial data", het achtergrondrapport bij het in 1999 uitgebrachte "Evaluatiedocument Lood". In tegenstelling tot wat eerder in de aanbiedingsbrief bij het "Evaluatiedocument Lood" (hoofdrapport) is vermeld, bevat het addendum alleen ecotoxicologische gegevens en geen gegevens over humaan-toxicologische effecten, wet- en regelgeving, stofeigenschappen en gedrag in het milieu en over concentraties en blootstellingniveaus, dit in overleg met de opdrachtgever (VROM/DGM, Directie Stoffen, Afvalstoffen en Straling). De niet opgenomen onderwerpen zijn in voldoende mate samengevat in het hoofdrapport of worden regelmatig geactualiseerd en gepubliceerd in andere rapportages zoals de jaarlijkse Milieubalans (met onderliggend Milieucompendium) en de vierjaarlijkse Milieuverkenning die door het RIVM worden opgesteld in samenwerking met andere instituten.

De in het addendum opgenomen ecotoxicologische gegevens hebben vooral betrekking op anorganisch lood; de gegevens voor organisch lood zijn zeer beperkt. De gegevens voor anorganisch lood zijn in het kader van de RIVM-projecten "Integrale Normstelling Stoffen" en het project "Risico's in relatie tot Bodemkwaliteit" gebruikt voor de afleiding van ecotoxicologische risiconiveaus, zijnde *Maximaal Toelaatbare Risiconiveaus (MTR-waarden)*, *Verwaarloosbare Risiconiveaus (VR-waarden)* en *"Serious Risk Concentrations" (SRC_{eco}-waarden)* voor anorganisch lood in bodem, grondwater, oppervlaktewater en waterbodem. Deze risiconiveaus vormen de basis van de huidige milieukwaliteitsnormen voor lood die door de Nederlandse overheid zijn vastgesteld. Zowel de risiconiveaus als de daarvan afgeleide milieukwaliteitsnormen voor lood zijn ook opgenomen in het addendum.

Met vriendelijke groet,

b/a

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